Roadway Hazard Analysis:
A Safe Ride for Motorcycles

by

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To those who have lost their lives in the data used for this thesis – you are more than a statistic.

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List of Abbreviations

AADT	Average Annual Daily Traffic
AGOL	ArcGIS Online
CU	Horizontal Curve
DGI	Department of Geographic Information
Esri	Environmental Systems Research Institute
EV	Rating Evaluation Section
GIS	Geographic information system
GISci	Geographic information science
GR	Grade or Vertical Curve
HLDI	Highway Loss Data Institute
IIHS	Insurance Institute for Highway Safety
KSP	Kentucky State Police
KYTC	Kentucky Transportation Cabinet
LN	Lane Width
OHSA	Optimized Hot Spot Analysis
NAD	North American Datum
NHSTA	National Highway Traffic Safety Administration
SL	Speed Limit
SSI	Spatial Sciences Institute
TF	Traffic Flow
USC	University of Southern California

Abstract

Motorcycles are disproportionately affected in collisions when compared to other motor vehicle types, leading to an increased vulnerability of injury or death to motorcyclists. Multiple factors can contribute to this disproportionate impact, including environmental factors, inattention of other motorists, driver error, and physical road characteristics. Many motorcycle safety initiatives address the error and role of other drivers in motorcycle-involved collisions but little attention is often given to the environmental and roadway factors. This lack of attention and analysis reduces the ability of transportation agencies to obtain a complete common operating picture for all factors impacting motorcycle safety – allowing for missed opportunities to decrease the increased vulnerability of motorcyclists.

This project utilized Geographic Information Systems (GIS) as a tool to identify locations on state-maintained roadways showing statistically significant clusters of motorcycle involved collisions. The collision data for this report were retrieved from the Kentucky State Police collision database; filters were used to extract motorcycle involved collisions for a ten-year period from 2009 and 2018. A site suitability study was completed using the collision data and road network layers to determine sites suitable to the introduction of a motorcycle lane in an effort to increase motorcycle safety. While there are multiple strategies for reducing motorcycle involved collisions, exclusive motorcycle lanes offer motorcyclists a safe location to ride without interference from other motor vehicles in areas with high traffic flow. Spatial analysis was utilized to complete a site suitability study to determine needed and viable locations for motorcycle lanes using Livingston, Jefferson, Fayette, and Meade County within the Commonwealth of Kentucky as a study area.

Chapter 1 Introduction

Motorcycle safety is a common transportation concern within the United States because of the increased vulnerability for injury or fatality to the rider. Despite only accounting for 3% of the vehicles on the road, motorcyclist fatalities comprise 14% of the total number of vehicle fatalities (NHSTA 2019). Commonly used for commuting or recreational purposes, motorcycles have many physical and structural differences when compared to other vehicles. These structural differences, coupled with environmental and roadway factors, often allow for a greater amount of injury to a motorcyclist if they are involved in a collision.

Multiple elements separate from vehicle design can increase the probability of a motorcycle involved collision. Some impacting factors include the physical roadway characteristics such as the roadway curve, pavement roughness, pavement type, curb presence, and grade. Others include environmental variables including weather and time of day, other motorist involvement, and negligence on the part of the motorcycle rider. The large number of potential factors makes actionable analysis difficult to perform when attempting to predict the probability or severity of a motorcycle involved collision. It also makes the creation of a comprehensive geospatial view of safety considerations and possible hazards to motorcyclists challenging and complex because of the vast amount of potential factors. Despite the difficulty of creating a common operating picture of all impacting factors, motorcycle safety can still be addressed and potentially improved by looking at existing crash data and then identifying the factors present in those locations to determine what actions can be taken to improve safety.

Geographic Information Systems (GIS) were utilized as a tool within this thesis to identify collision hot spots involving motorcycles occurring over a ten-year period, allowing for potential locations needing infrastructure improvements to be identified. Once hot spots had been identified according to certain parameters, additional analysis was performed to detect hot spots overlaying a crash factor tied to the Average Annual Daily Traffic (AADT) amount. As will be discussed in the literature review, the AADT of an area can indicate a higher presence of motorcycle and other vehicle interactions, which can lead to higher probabilities of a motorcycle-involved collision. This analysis was performed to identify locations that may be a suitable location for the introduction of motorcycle lanes to the existing road infrastructure. Motorcycle lanes can reduce the number of motorcycle-involved collisions, as the lane offers motorcyclists a safe location to ride without interference from other motor vehicles. Spatial analysis was utilized to complete a site suitability study to determine needed and viable locations for motorcycle lanes in a specified area. The completion of this spatial analysis by this project can also help transportation agencies identify and address roads that pose an increased risk to motorcycle safety even if a motorcycle lane is not viable because of space constraints.

A foundation of knowledge for motorcycle risk on roadways was gained by reviewing identified motorcycle crash factors, roadway engineering, and infrastructure improvement studies, and existing mobile motorcycle applications. The findings from this review are included within the Related Work chapter of this document. Case studies covering the introduction of vehicle-specific travel lanes and motorcycle safety initiatives provided additional identification of factors impacting motorcycle crash rates and viable countermeasures to reduce the risk of a collision. The resulting information from a review of the above topics was utilized in guiding the spatial analysis for this project within the designated study area. The study area for this project is the Commonwealth of Kentucky due to data accessibility and researcher location.

1.1. Motivation

Motorcyclists are disproportionately injured or killed in crashes when being compared to other motor vehicle occupants. As mentioned above, motorcyclist fatalities compromise 14% of the total number of vehicle fatalities within the United States although they only account for 3% of the vehicles on the road (NHSTA 2019). While this percentage fluctuates slightly from year to year, the trend stays consistent: motorcyclists are more susceptible to injury or death resulting from a collision. The motivation for this thesis stems from three inter-related components: the natural vulnerability of motorcyclists, crash statistics and trends, and an overarching lack in applied hazard analysis research on motorcycle safety.

1.1.1. Natural Vulnerability

Motorcycles have an inherent risk of greater injury to riders because of their design and structure. They weigh less than other vehicles, contributing to crash severity and injury of the rider in the event of a collision or crash (Rezapour 2019, 108). The smaller frame of a motorcycle can make it difficult for other motorists to see – they are less visible and often hit as a result. The majority of crashes involving motorcycles and other vehicles occur because the other vehicles did not see the motorcycle, resulting in a reduced reaction time to successfully redirect and avoid a collision (NHSTA 2019). Roads are also typically designed for automobile use (Nabor 2016, 10) and certain aspects can increase the probability or impact of a collision on a motorcyclist. Shoulder types (i.e. curb or flat), traffic control devices, curves, and pavement conditions can increase the severity of a motorcycle involved collision despite being considered safe or a necessary part of designing the roadway for general automobile use.

Motorcycles are less stable than other vehicles because of their smaller frame and design; they offer a reduced amount of protection to the rider in the event of a collision (IIHS HLDI

2019). Part of the stability issue stems from the two-wheel design – motorcycles have a higher degree of instability because of the two-wheel design as opposed to the four-wheel design of other motor vehicles. This instability gives motorcyclists a higher level of vulnerability while riding that their counterparts in four wheeled vehicles may not be susceptible to - the impact of variations in road geometries and surface conditions can increase the probability of a motorcyclist losing control and having a collision (Daniello et al. 2010, 27). Figure 1 references the common differences between motorcycles and other motor vehicles. This image was a part of a motorcycle safety campaign from the Texas Department of Transportation and it helps exemplify the structural differences which increase the vulnerability of the rider (Texas Department of Transportation 2019). The natural vulnerability and reduced amount of protection to the motorcycle rider resulting from the motorcycle design is part of the motivation for analyzing motorcycle collisions within this thesis.

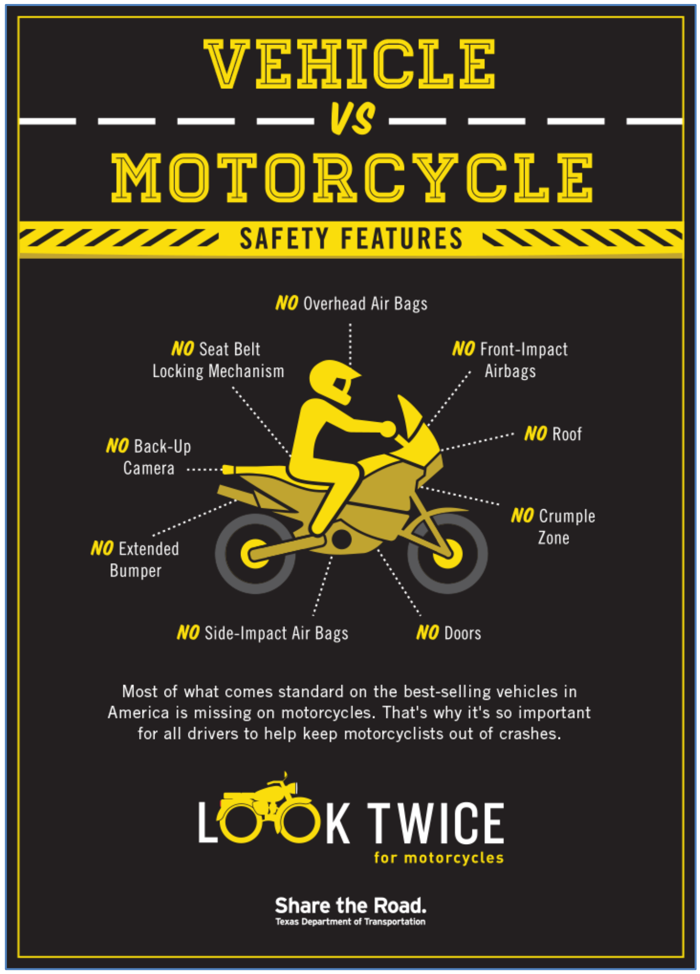


Figure 1. Motorcycle comparison

1.1.2. Statistics and Trends

Compounded with the inherent vulnerability of the motorcycle as a vehicle type because of the structural design, motorcycles offer a reduced amount of physical protection to riders . The smaller frame, lack of seatbelt and airbags, and lack of doors and a roof decrease the physical protection to riders and their passengers in the event of a collision (Texas Department of Transportation 2019). The reduced physical protection contributes to a higher injury and fatality rate when compared to the injury and fatality rates of other vehicle occupants. The Highway Loss Data Institute (HLDI) within the Insurance Institute for Highway Safety (IIHS) reported 5,172 motorcyclist fatalities in 2017 (HLDI IIHS 2018) and in 2016, they reported the number of motorcyclists killed on roadways was 28 times higher than the number of deaths for other vehicular traffic. The National Highway Traffic Safety Administration (NHSTA) elaborated on the 2017 fatality total, stating motorcyclist deaths account for 14% of traffic deaths despite motorcycles only comprising 3% of vehicles on the roadway. These statistics indicate a disproportional relationship between expected vehicle motorist fatalities and actual motorcyclist fatalities. The historically disproportionate impact on motorcyclists is part of the motivation for evaluating motorcycle involved collisions within this thesis.

1.1.3. Existing Hazard Analysis

The existing hazard analysis for motorcycle collisions identifies a myriad of factors which can impact motorcycle safety on roadways but the application of mitigation strategies to reduce the impact of those factors is not as pronounced. Identifying factors impacting motorcycle safety is crucial in reducing the risks and hazards motorcyclists face but action still needs to be taken to increase the safety of these riders through mitigation strategies. The application of mitigation strategies including physical initiatives and roadway alterations to address identified factors impacting motorcycle safety is minimal within existing literature. It is necessary transportation agencies are aware of the hazards and dangers their roadways pose to motorcyclists but the next step of addressing those factors is critical to improve motorcycle safety.

Aligned with the importance of transportation agencies being able to identify factors having an impact on motorcycle safety, it is vital for motorcyclists on the roadways to be able to identify potential hazards as they are riding. The concept of hazard perception addresses the ability of a rider to perceive a threat and avoid impact while riding by altering their actions (Cheng 2011). Motorcycle riders who had experienced collisions were shown to have a lower level of risk perception, which may have contributed to their collision(s). Contrarily, motorcycle riders who have not experienced a collision were shown to have a higher level of risk perception. The concept of risk perception by motorcyclists lends support to the need to address potential hazards and crash factors when they are identified – the impetus of applying mitigation techniques to known collision factors to increase safety and reduce vulnerability.

Factors which can impact the probability of a motorcycle involved collision occurring have been identified and will be further covered in the literature review section of this document. The benefit of this project is offered in the application and use of those factors to determine roadways that could benefit from motorcycle lanes and / or additional action by the transportation cabinets. This project explores the identified factors impacting motorcyclist safety and creates a geospatial product that displays hot spots for motorcycle involved in collisions coupled with factors shown to have an impact on motorcycle safety. The research combined existing data on motorcycle collisions, data on factors impacting motorcycle collisions, and mitigation strategies in an effort to begin addressing the gap within the existing literature.

1.2. Study Area

Four counties within the Commonwealth of Kentucky were selected as viable study areas for this project: Livingston County, Meade County, Fayette County and Jefferson County. Visible in Figure 2, these counties were selected as a result of analyzing motorcycle collision data between 2009 and 2018 collected from the Kentucky State Police's (KSP) crash information website (KSP, 2019). For the ten-year period, these counties experienced either a higher cumulative collision amount, a higher probability of a collision resulting in an injury, or a higher probability of a collision resulting in a fatality. The four counties were analyzed as separate study areas to ensure the hot spots within that county were identified without interference or influence from a different county's collision records. This assisted in evaluating motorcycle safety and the completion of this project's objective. Although the study areas are specific to Kentucky, the methods used for determining site suitability can be used for locations outside of Kentucky.

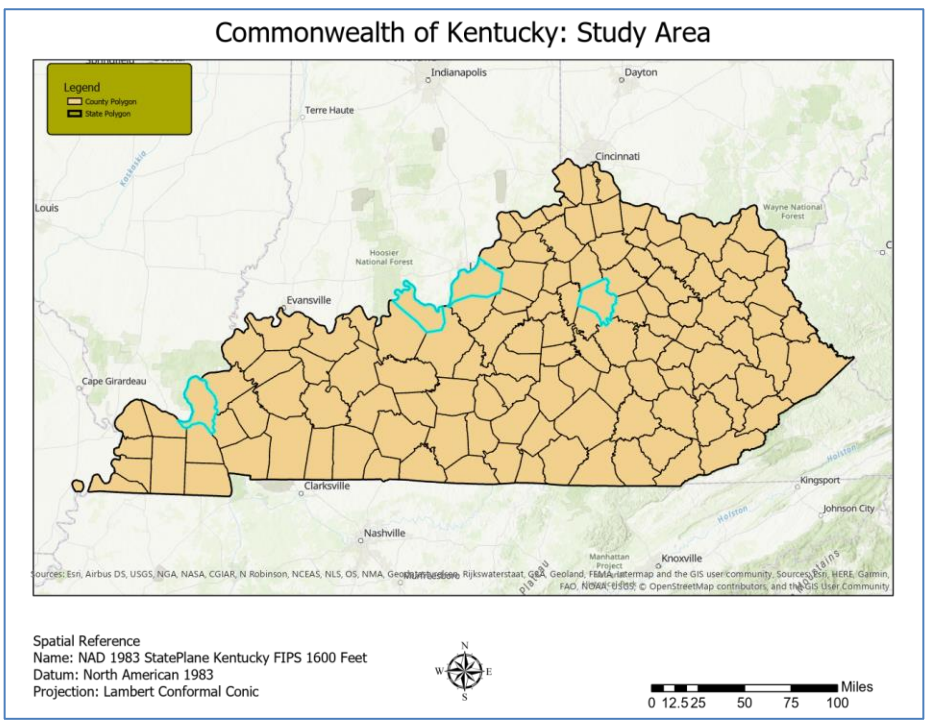
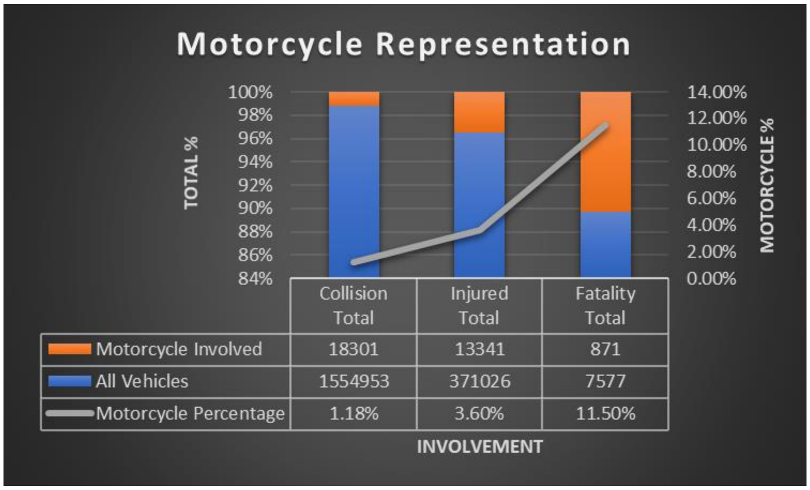


Figure 2. Commonwealth of Kentucky

1.2.1. The Commonwealth of Kentucky

The Commonwealth of Kentucky was selected as the location for research because of data accessibility and researcher location. Located in the east central portion of the United States, Kentucky has over 3.5 million registered vehicles including 94,675 registered motorcycles (1.23%) (DataMart 2019). Comprised of 120 different counties split between 12 Highway Districts, Kentucky is home to a variety of geographic features spanning the 27,500 + miles of state-maintained roads. A portion of these state-maintained roads are named Scenic Byways because of the "scenic, natural, cultural, historical, archaeological, and/or recreational" nature of the roadway viewshed (DGI, 2019). The recreational nature of these routes can make them preferred travel routes for recreational motorcycle riders and they, along with the remaining state-maintained roadways, were evaluated within this project.

The average for motorcycle involved fatalities is lower in Kentucky as a whole when compared to the 2017 national average of 14%, as referenced by a ten-year spread of fatality counts shown in Figure 3. Despite a lower fatality average, motorcyclists are still disproportionately represented in injury and fatality counts as shown in Figure 4. Between 2009 and 2018, motorcycle involved collisions accounted for 1.18% of all vehicular collisions in Kentucky. The injuries resulting from motorcycle involved collisions, however, represented a higher percentage of overall injuries at 3.6% and an even higher percentage of fatalities at 11.5%. The figures below help demonstrate the increased and



	Collision Total	Injured Total	Fatality Total
Motorcycle Involved	18301	13341	871
All Vehicles	1554953	371026	7577
Motorcycle Percentage	1.18%	3.60%	11.50%

Figure 3. Motorcycle representation

disproportional vulnerability for individuals impacted by motorcycle involved collisions. The study area focus was narrowed down from all of Kentucky to the specific counties having higher percentages of overall collisions, injuries, or fatalities over the ten-year spread of collision data. Once the study area was reduced to four specific counties, the factors shown to impact motorcycle crash rates and existing crash data were evaluated in support of the objective of this paper.

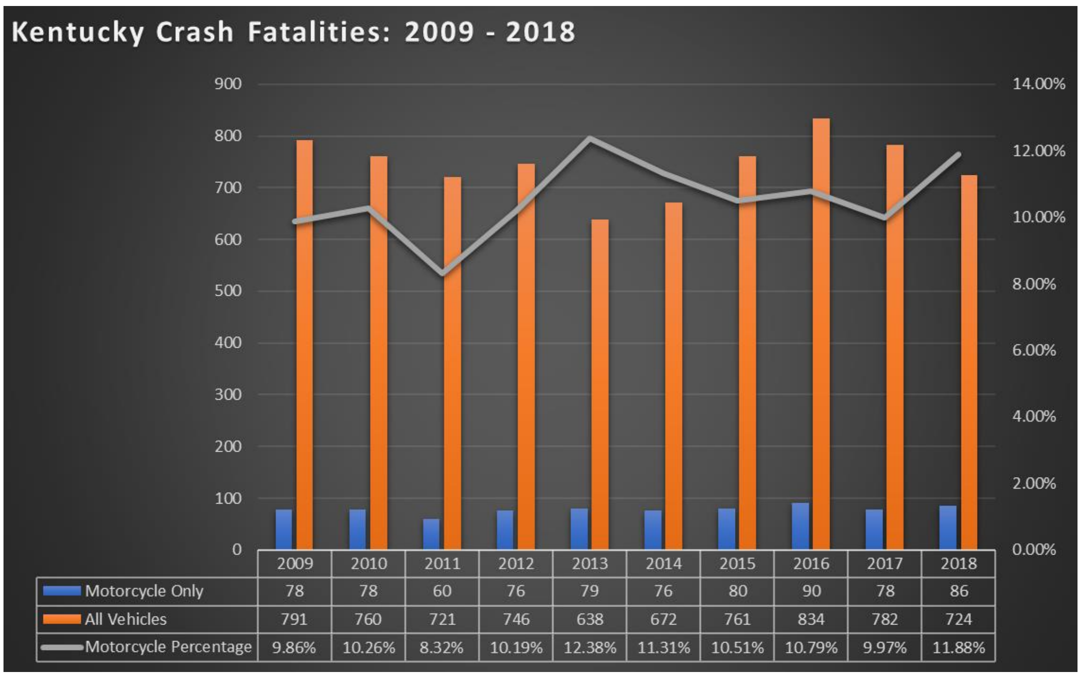


Figure 4. Kentucky crash fatalities

1.2.2. Livingston County, Kentucky

After reviewing the crash data, motorcycle-involved collisions were more likely to lead to an injury within Livingston County – prompting the inclusion of the county as a study area. Motorcycle collisions in Livingston County between 2009 to 2018 resulted in a higher percentage of injuries when being compared to the total number of motorcycle involved collisions on the county level. Kentucky State Police recorded 57 collisions involving motorcycles, resulting in 60 injuries (Kentucky State Police 2019). There were a higher number of injuries recorded than there were collisions, meaning multiple injuries resulted from collisions during this time period. Comparatively, while Livingston County did not have the highest percentage of injuries for Kentucky, the county did have the highest percentage of injuries coupled with the highest injury count. Refer to Figure 5 for a chart of the counties with the highest injury percentage stemming from motorcycle involved collisions.

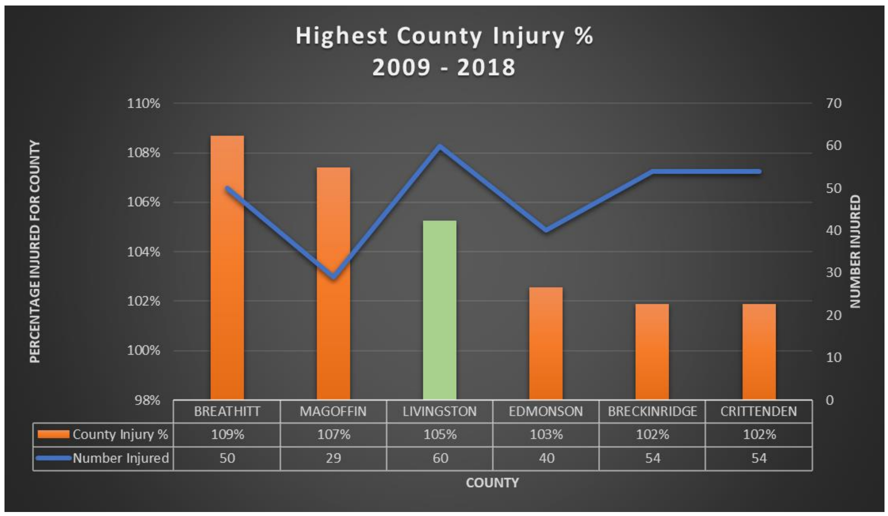


Figure 5. Highest county injury percentage

Livingston County is located in western Kentucky and is a part of KYTC District 1. The county has a low population with 9,519 residents and compromises 342.32 square miles (DataMart 2019). There are 416.7 miles of state-maintained roadways which were evaluated within this project. The Kentucky Transportation Cabinet has 8,764 registered vehicles within the county and 268 of those registrations are motorcycles. Despite Livingston County being one of Kentucky's smaller counties, benefit can be gained by using the county as a

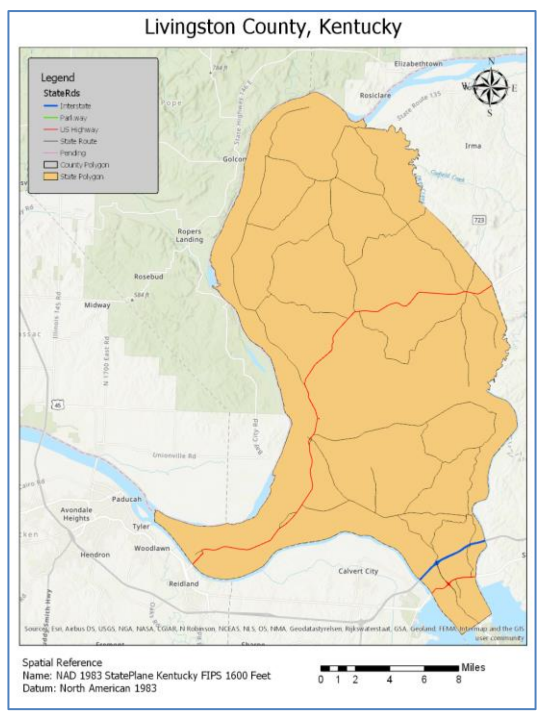
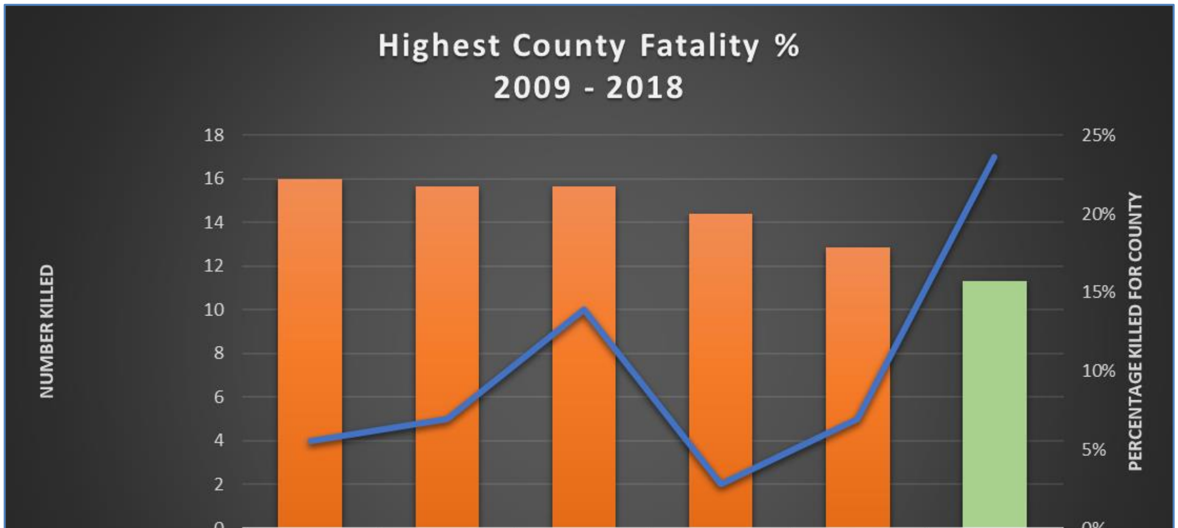


Figure 6. Map of Livingston County

study area. Livingston County has a higher percentage of injuries resulting from motorcycle involved collisions and can benefit from an analysis of existing crashes and identified motorcycle crash factors. Refer to Figure 6 for a map of Livingston County and the state-maintained roadways within the county.

1.2.3. Meade County, Kentucky

Similar to Livingston County, Meade County was included as a study area because of the higher percentage of motorcycle involved collisions resulting in a fatality; the collision data revealed individuals had a higher change of dying from a motorcycle involved collision in Meade County. Motorcycle collisions in Meade County between 2009 and 2018 resulted in a higher percentage of fatalities when compared to the total motorcycle involved collisions recorded for the county. There were 17 fatalities for the 108 motorcycle involved collisions recorded over the ten-year period (Kentucky State Police 2019). The percentage of fatalities resulting from a collision for this county was 16% and while this is not the highest fatality percentage for all counties within Kentucky, it is the highest percentage coupled with the highest



	OWSLEY	LEWIS	WAYNE	LESLIE	BATH	MEADE
County Fatality %	22%	22%	22%	20%	18%	16%
Number Killed	4	5	10	2	5	17

Figure 7. Highest county fatality percentage

recorded fatality count. Refer to Figure 7 for a summary of the six counties with the highest resulting fatality percentage.

Located in KYTC Highway District 4, Meade County, Kentucky has 24,580 registered vehicles with 910 of those being registered motorcycles (DataMart 2019). With a population of 28,602, the county covers 324.43 square miles and is located in south central Kentucky. The county has over 500 miles of state-maintained roadway that were evaluated to determine locations that could be addressed to improve motorcycle safety and reduce the resulting injuries and fatalities from motorcycle involved collisions. Refer to Figure 8 for a map of Meade County displaying the state-maintained roads within the county.

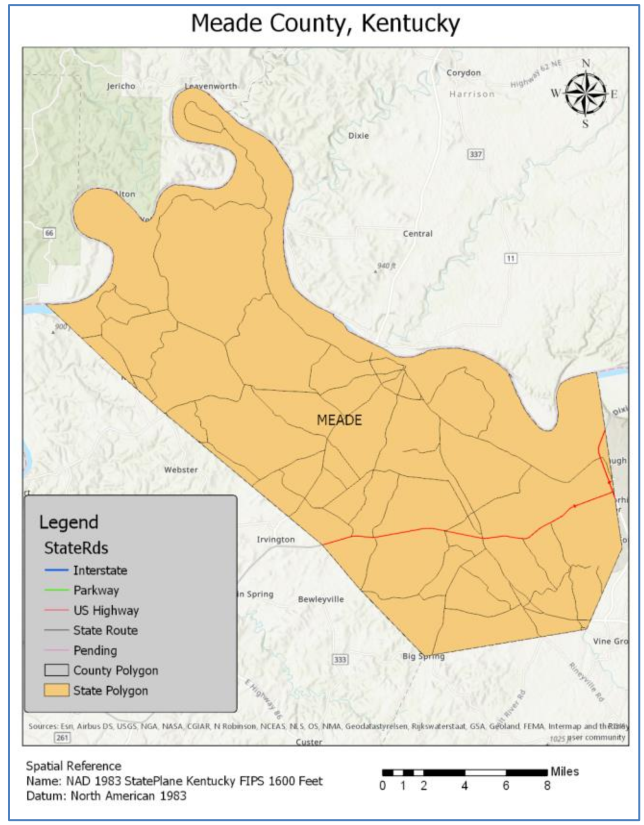


Figure 8. Meade County

1.2.4. Jefferson County, Kentucky

Jefferson County experienced the highest cumulative amount of motorcycle-involved collisions between 2009 and 2018 and was included as a study area. In this ten-year period, 3,160 collisions involving a motorcycle were recorded, resulting in 2,306 injuries and 142 fatalities (Kentucky State Police 2019). As shown in Figure 9, 10, and 11, Jefferson County experienced the highest cumulative amount of injuries, fatalities, and collisions.

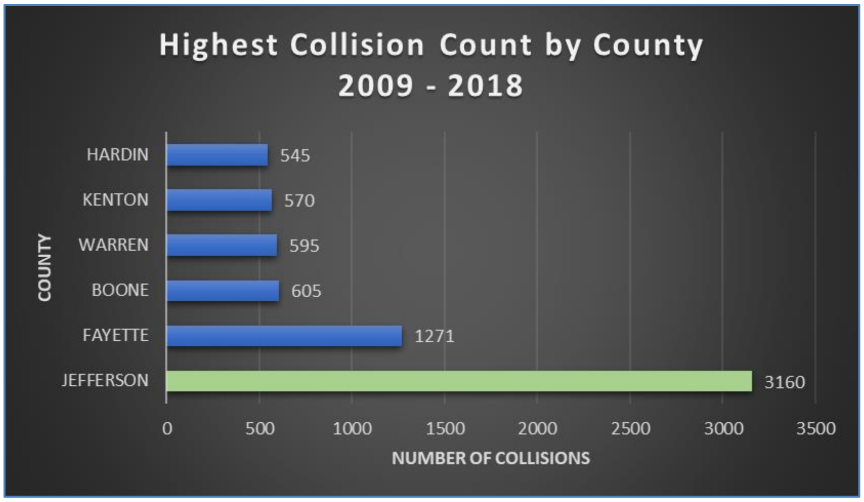


Figure 9. Highest collision count by county

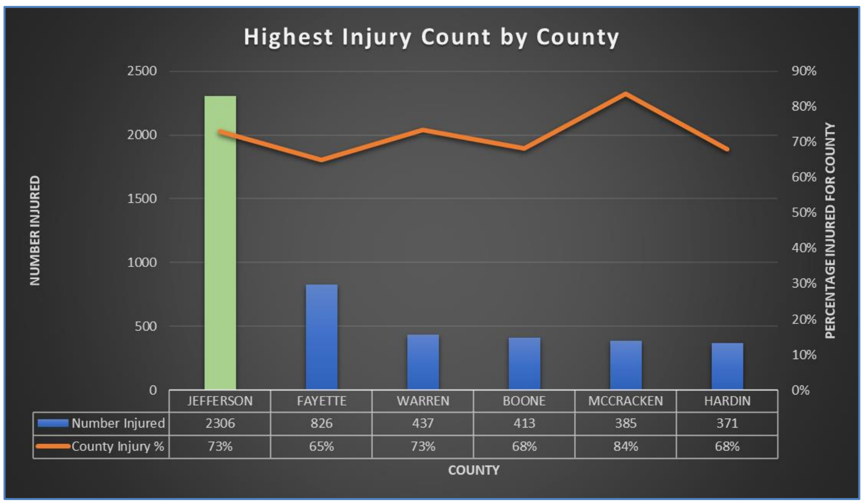


Figure 10. Highest injury count by county

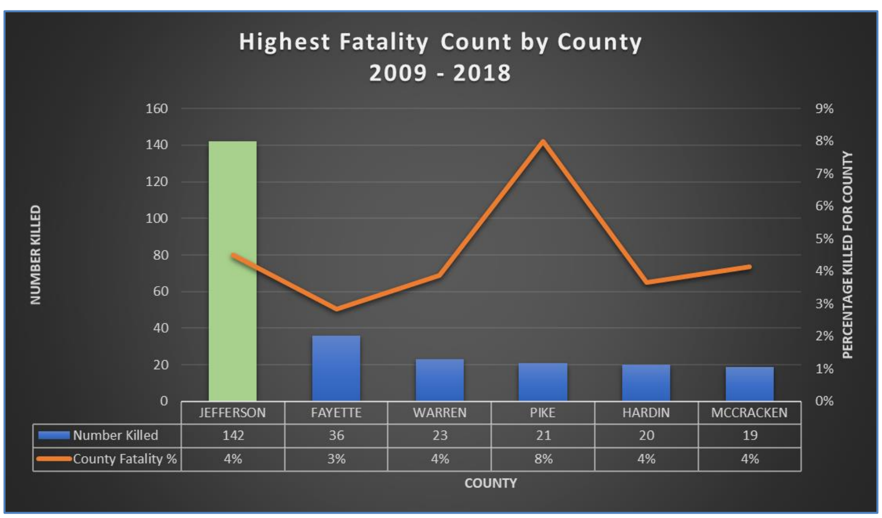


Figure 11. Highest fatality count by county

Jefferson County has the highest population of the four study areas with 741,096 people although the county covers an area similar to the other study areas: 397.61 square miles (DataMart 2019). Located in KYTC District 5, Jefferson County has 1,952.2 miles of state-maintained roadway that were evaluated within this study for identified motorcycle crash factors. There are 571,473 vehicles registered to the county with 12,161 of those vehicles being motorcycles. Refer to Figure 12 for a map of Jefferson County.

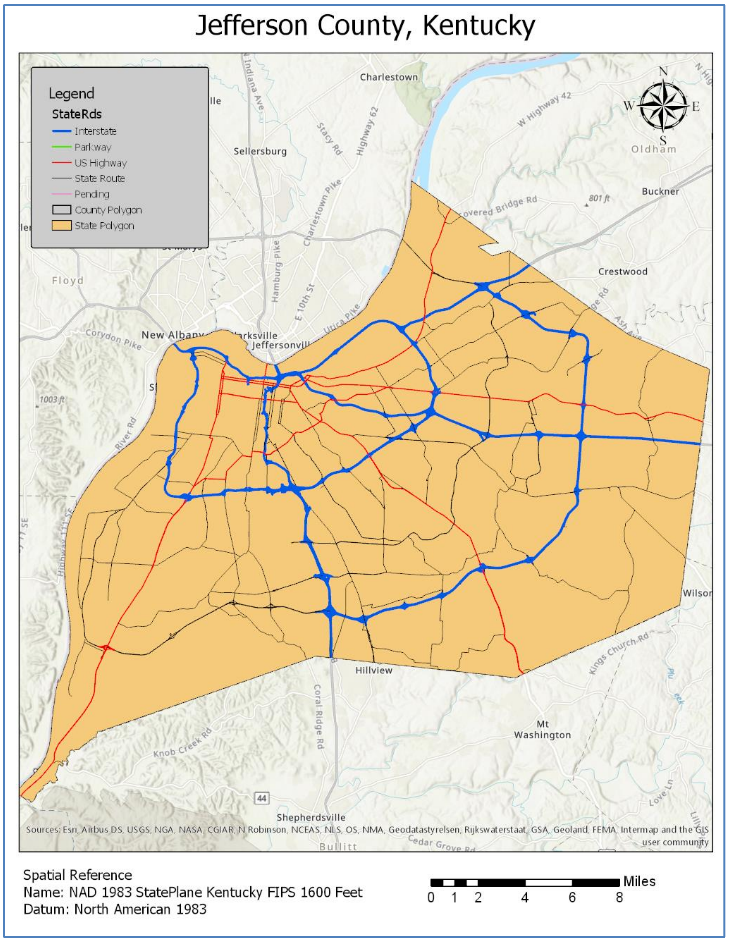


Figure 12. Jefferson County

1.2.5. Fayette County, Kentucky

Fayette County was selected as a viable study area because the county had the second highest cumulative count of motorcycle involved collisions (Figure 9), resulting injuries (Figure 10), and resulting fatalities (Figure 11). In this ten-year period, 3,160 collisions involving a motorcycle were recorded, resulting in 1,271 injuries and 36 fatalities (Kentucky State Police 2019). It is important to note Fayette County was not originally included as a study area but was selected after analysis had begun because of inconclusive results for portions of the analysis conducted on Livingston and Meade counties. This will be explained further in the Results chapter of this document.

Fayette County, located in central Kentucky, has a population of 295,803 people and is the smallest of the study areas with an area of 285.49 square miles (DataMart 2019). Located in KYTC District 7, Jefferson County has 920.1 miles of state-maintained roadway that were evaluated within this project. There are 219,100 vehicles registered to the county with 4,812 of those vehicles being motorcycles. Refer to Figure 13 for a map of Fayette County

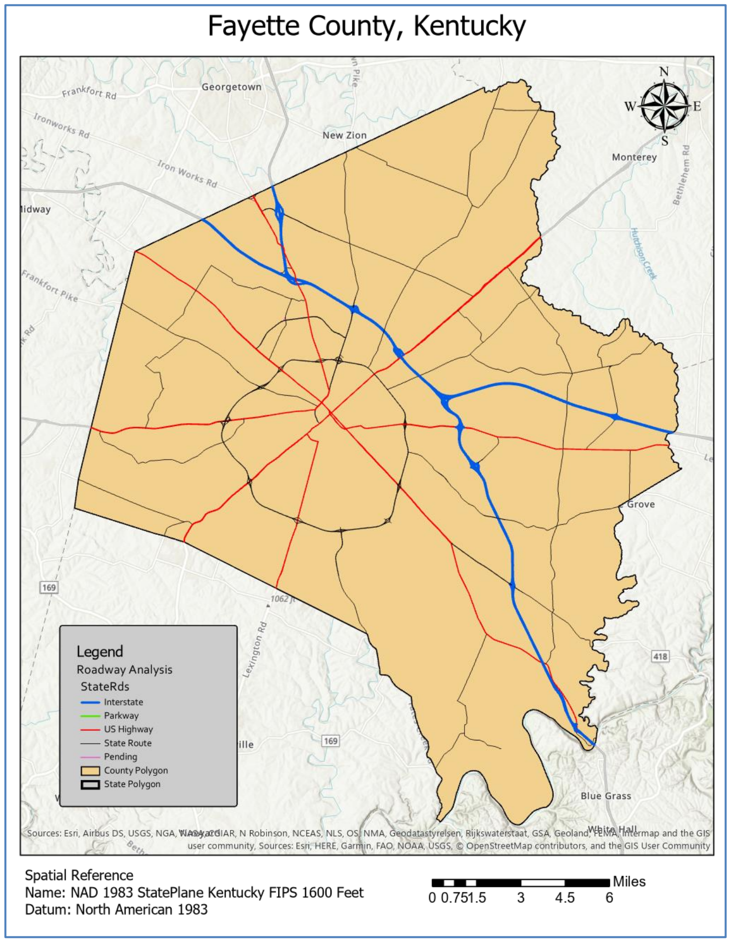


Figure 13. Fayette County

1.3. Thesis Organization

The following chapters within this document are designated for overarching components of work completed for this project. The introduction and foundation have been laid in Chapter 1, where the motivation and crux of the problem this project addressed was introduced: is it possible to determine locations on state-maintained roads needing mitigation measures to increase motorcycle safety? Chapter 2 looks at related work to motorcycle safety and the critical components needed to be understood for a comprehensive, actionable analysis. The third chapter of this document addresses the research methods, identifying and justifying the tools used for analysis and outlining the procedures followed. Chapter 4 reveals the overall results per study area, defining the issues encountered and limitations of the findings. The final chapter, Chapter 5, contains the conclusion, application, considerations, and next steps for this project.

Chapter 2 Related Work

While research exists relating to motorcycle safety, there is an identifiable gap in the application of that research to efforts aimed at making roadways safer for motorcyclists. A plethora of research on potential factors impacting a motorcycle's traversement of roadways and safety measures that can reduce motorcyclist vulnerability exists. There are multiple mobile applications in production for Apple and Android devices a well geared toward increasing motorcycle awareness and discovering / sharing safer riding routes. The research mentioned above starts to create a picture of what motorcycle safety is and the various factors which impact it. There is still a gap, however, in literature on combining the motorcycle mobile applications, crash statistics, collision factors, and knowledge of mitigation measures for the improvement of roadway conditions linked to motorcycle crashes. The existing literature has few examples covering the application of safety measures to identified hazards.

2.1. Identified Factors

Identified factors in motorcycle collisions include roadway characteristics, other motorist involvement, and negligence on the part of the motorcycle rider. The case studies identifying motorcycle crash factors contain various study areas, some with inherit differences when comparing the location to the project study area of Kentucky. These studies still provide valuable insight into the factors affecting motorcycle safety. It is also important to note multiple studies follow an approach of separating crash statistics into specific categories: motorcycle only incidents, motorcycle and a single vehicle, and motorcycle and multiple vehicle collisions. This delineation into data categories was adopted within this project as the factors impacting collisions vary slightly based on the category of collision.

A prominent factor impacting motorcycle collisions is other drivers. In Victoria, Australia, a study identified multiple factors as playing a role in motorcycle collisions with the primary factor being other road users (Allen 2017, 157). Additional factors include rider age, the traffic density of an area, speed of the rider and other vehicles, and road design issues. While it is difficult to account for the human element of other drivers in a predictive, geospatial context, analyzing the Average Annual Daily Traffic (AADT) can be useful. AADT reflects the average traffic density on roadways – it is used to account for higher traveled roads where there is an increased interaction between motorcyclists and other drivers.

It is important to note additional research suggests a variable use of AADT as a factor impacting motorcycle crashes. There are multiple studies pointing to traffic density and interactions with other drivers as a primary factor in motorcycle collisions (Sohadi 2000, 11) but a contrary viewpoint needs to be considered (RideApart 2018): an inverse relationship to traffic density and motorcycle crashes can be found in rural areas. The logic is that in lower traffic density areas, motorcycles are not expected to be common and consequently are involved in collisions because other vehicular traffic did not stop to look twice for them and they crossed the path of the motorcycle. This clarification is important because it can affect the analysis performed on high density and low density roadways when working with the traffic density or AADT variable. Within the context of this project, the AADT for a roadway is analyzed to determine the severity of the increased interaction between motorcyclists and other drivers.

A case study in Wyoming reviewed factors impacting vehicles in downgrade collisions (steep downward slopes and hills / mountains) and identified lane width and speed as viable factors (Rezapour 2019, 115). Despite the focus of this case study being on mountainous areas, the results can still be used because it highlights factors which need to be monitored in areas with variable grade. Additional motorcycle crash factors include roadway curve, presence of driveways, two lane roads (Schneider 2012, 673), topography, presence of construction, road geometries, railroad crossings, road condition, wildlife presence, and jurisdictional information leading to population density (Ramirez 2016). Bridges along a roadway can also impact the probability of motorcycle collisions as the bridge condition and approach affect the overall rideability and ease of crossing the bridge (Murthy 1990). Uneven surfaces can enhance the instability of motorcycles – a bridge approach in poor condition can knock a motorcyclist off balance and contribute to a potential collision.

2.2. Motorcycle Specific Mobile Applications

Mobile applications are being included within the literature review as they provide context for the applications used by the motorcycle community and the applications help identify factors which can impact motorcycle safety. As motorcycle usage increases, it is important to be aware of what goes into the selection of a route for riding and the considerations of a rider. While it is difficult to find mobile motorcycle application in peer reviewed and scholarly journals, web browser searches return a plethora of results for applications widely used within the motorcycle community. Many applications can also be used outside of the motorcycle community including gas availability applications, weather reports, and lodging applications. These are often returned as "motorcycle" mobile applications because of the recreational nature of motorcycle use. For the duration of this project, any reference to motorcycle mobile applications will not refer to this last example of mobile applications.

Eat Sleep Ride is a mobile application combining functionality types for motorcycle riders (BikeBandit 2018; Guido 2017; Gales 2017). It allows users to track, create, share, and find existing motorcycle routes. The value from this application is the information collected and stored with routes – the duration, level of difficulty, hazardous nature, etc. These route selection factors begin to create an understanding of factors motorcyclists consider when determining a safe route to ride.

A similar application, Rever, also facilitates route sharing (BikeBandit 2018; Guido 2017; Gales 2017) by allowing riders to record and share routes with various metrics. These metrics include speed, distance, and elevation changes which were identified as factors potentially impacting the probability of a motorcycle crash. A Road Segment Safety Rating System application (Ramirez 2016) identified as a US Patent Application also assists motorcyclists with finding safe routes. This application uses a rider-provided starting and ending point and then calculates the safest route for the motorcyclist to travel. The application reviews a set of road ratings and routes the motorcyclist on the route with the highest ratings. This application can be further reviewed to determine how the roads are chosen and which metrics the application uses.

2.3. Current Safety Initiatives

Current Safety Initiatives can help identify viable practices that increase or promote motorcycle safety. Examining safety initiatives undertaken in various states and countries helps identify the underlying causes impacting motorcycle involved collisions and it provides possible mitigation practices for improving motorcycle safety. Hazards to motorcyclists can be segregated into two categories: hazards stemming from the road itself – the infrastructure or environment portion, and hazards stemming from behavior – and/or the rider or other motorists (Cheng 2011). To assist with structuring a review on safety initiatives, the mitigation measures of safety initiatives have been separated into similar categories for the behavior-based initiatives and infrastructure-based initiatives.

2.3.1. Behavior-Based Initiatives

Behavior-based initiatives are meant to increase motorcycle safety by mandating or encouraging changed behavior – they do not address changing the infrastructure of the road or road assets but profess that through behavioral change, the level of safety for motorcyclists can be increased. An example of a behavior-based initiative can be found in Australia. Motorcycle crashes in Victoria, Australia, were evaluated to determine collision factors and multiple safety improvement suggestions were provided (Allen 2017,165). These suggestions include white helmets (a 33% reduction in crashes), reflective clothing (a 24% reduction in crashes), and additional safety measures including re-evaluating posted limits and speed enforcement for riders traveling over the speed limit. While these suggestions do not address the physical element of the roads themselves, they do address factors which may lead to motorcycle involved collisions including visibility and driving safety.

Road signage, media engagement and education, and inspection rides are additional behavior-based initiatives pursued in various countries and states. In North Carolina, a segment of roadway was evaluated in a Road Safety Audit (RSA) between 2012 and 2014 (Nabors 2016, 13). This segment of roadway had multiple recorded motorcycle involved collisions. As opposed to changing the road infrastructure, signage specific to motorcyclists was added alerting them to the road conditions (i.e. a sharp curve) which could impact them. In London, additional signage was used for motorcyclists within work zones to alert riders to pavement changes, construction debris such as loose gravel, and splash warnings (Nicol 2012, 8). Similar practices are used within Norway, Belgium, and the United Kingdom where signs are placed for the benefit of motorcyclists as well as other automobile drivers. In Norway, rides are organized with local motorcyclists to inspect routes – these are called "road quality rides" and they are intended to allow for reporting on pavement and road conditions, clear debris, and report any potential concerns that may lead to a motorcycle involved collision. Engaging local groups as Norway did is a successful example of a behavior-based initiative that allows for motorcycle safety and awareness to increase without costly and potentially unneeded infrastructure changes.

Training classes are another layer of behavior-based initiatives that can lead to an increase in motorcyclist safety and a potential reduction in motorcycle involved collisions. Basic training courses are not required in all states within the United States and trends have shown that most riders who do attend the basic courses do not continue their motorcycle safety education, failing to take advanced courses (Nabors 2016, 10). When compared with other automobile drivers, motorcyclists have a higher instance of having collisions with objects which are fixed and not moving. Encouraging advanced training courses within an initiative could help reduce this fixed object collision rate because of the maneuvers taught in the advanced courses. These safety initiatives highlight factors which may impact the probability of a motorcycle involved collision and they provide factors which can be monitored in areas containing either fewer or an excess of motorcycle collisions.

2.3.2. Infrastructure-Based Initiatives

Infrastructure-based initiatives are meant to increase motorcycle safety by addressing the infrastructure of the road and / or road assets and can be costly but needed and rewarding endeavors. An example of an infrastructure-based initiative can be found in Norway (Nicol 2012) and North Carolina (Nabors 2016) where paved aprons are created where gravel or dirt roads meet paved roads. An apron is a section of the roadway entrance where two roads meet. By creating a paved entrance to the gravel or dirt road, there is a reduced amount of debris (dirt and gravel) entering the traveled path of the paved road as vehicles turn and weather washes debris across the road. If left uncleared or allowed to accumulate, debris on the roadways can create an unstable riding environment and potential hazards for motorcyclists.

While signage was mentioned in the behavior-based section, modifying existing signage is an infrastructure-based initiative aimed at increasing motorcycle safety for line of sight and potential collisions. In Norway, road signs on multiple posts were consolidated to occupy one post with multiple signs (Nicol 2016, 9). This can reduce visual obstructions which may distract from or hide motorcyclists. Additionally, the construction of the sign posts was changed to a lattice appearance to reduce the severity of injury in the event motorcyclists collided with signage on the side of the road

In Malaysia (Radin et al. 2000, 11), traffic flow, also discussed within the factor section of the literature review, is being used to justify the use of motorcycle lanes in a government initiative to increase motorcycle safety. The majority of traffic fatalities (nearly 60%) within Malaysia were motorcyclists and, despite the country having a higher percentage of motorcycle riders, the impact to motorcyclists in collisions was disproportional (Law 2005, 3372). Infrastructure changes were evaluated and the solution of motorcycle-exclusive lanes was decided on. These lanes, approximately 3.81 meters (12.5 feet), were introduced on roadways with over 60,000 AADT (Radin et al. 2000) in an effort to reduce collisions and the results were successful. Opening a motorcycle lane was shown to reduce collisions by 39%, partly because it reduced the interaction of vehicles and motorcycles traveling at different speeds. This example of a current safety initiative lends support to traffic flow being a viable factor impacting motorcycle collisions as well as motorcycle lanes being an appropriate response to an issue for motorcycle safety. Within this project, motorcycle exclusive lanes were the infrastructure-based initiative being reviewed for site suitability. This is further discussed within the Methods chapter.

Chapter 3 Data and Methods

The objective of this project was to determine suitable and viable locations for motorcycle lanes on state-maintained roadways in Kentucky. This was accomplished by using GIS as a tool to evaluate motorcycle collision locations from 2009 to 2018. After reviewing the data, several study areas were selected within Kentucky. Several methodologies were considered and evaluated to accomplish this objective. The first route evaluated involved using Esri's Network Analyst to assign a route a severity rating based on the presence of existing hazards from the road infrastructure. This route was not pursued after the initial evaluation because the tool did not allow for the identification of locations needing infrastructure improvement – it was more suitable for determining routes with a higher or lower rating score based on multiple factors. The second route evaluated for completing this project's objectives involved using a different tool (the Optimized Hot Spot Analysis Tool) and it is outlined below.

GIS was used to complete a technical hot spot analysis for collisions according to various parameters. Identified hot spots were then evaluated to determine if they were located on state-maintained roads and segments with an Average Annual Daily Traffic (AADT) value of over 60,000 were then isolated. The resulting roadway segments were evaluated for lane-widening potential to determine which locations could support the infrastructure addition of a motorcycle lane. The use of motorcycle lanes in collision-prone locations showing a higher AADT could act as a viable motorcycle safety approach to reduce the number of motorcycle-involved collisions. This reduction in motorcycle-involved collisions can also potentially reduce the number of collision related injuries and fatalities.

3.1. Data Description

Multiple datasets were evaluated in determining suitable locations for motorcycle lanes. The data being used in this project was grouped into three, theme-based categories: base or jurisdictional information, crash factors, and recorded crash locations. Throughout the project, different types of analysis were used for the three categories. The sections below identify the data within the categories and the analysis performed in determining suitable locations for motorcycle lanes.

3.1.1. Jurisdiction and Base Layers

Various jurisdictional boundaries and base data layers were used within this project for summation information and visual display. The boundaries for the Commonwealth of Kentucky and counties within Kentucky were collected as shapefiles from the Department of Geographic Information's (DGI) geoportal (2019) which acts as a platform for state and local agencies to publish data layers. These layers are open to the public and maintained/updated by DGI. They are both polygon layers and can be added to a map document, giving the ability to access summation information, clip other layers, and allow for a visual representation of the study area.

Road centerlines were used as a data layer within this project for visual display, as a base layer, and for road segment identification. Two separate layers were used: one to represent the state-maintained roadways, and one to represent local-maintained roadways. Both layers were obtained as shapefiles through the DGI geoportal. The Kentucky Transportation Cabinet (KYTC) utilizes the geoportal to publish various data layers for public consumption. Table 1 displays additional information on the jurisdiction and base layers which were used within this project.

Table 1. Jurisdiction and base layers

Dataset	Source	Scale	Precision	Accuracy	Purpose
Kentucky Boundary	DGI	NAD 1983 StatePlane Kentucky FIPS 1600 Feet	Vector Polygon	95% Confidence the accuracy is between 0.5 and 2.0 Meters	Jurisdictional boundary for visual identification and data management
County Boundary	DGI	NAD 1983 StatePlane Kentucky FIPS 1600 Feet	Vector Polygon	95% Confidence the accuracy is between 0.5 and 2.0 Meters	Jurisdictional boundary for visual identification and data management
Road Centerlines – State and Local	KYTC through DGI	NAD 1983 StatePlane Kentucky FIPS 1600 Feet	KYTC maintains data collection standards for road centerlines and associated attributes to help increase the precision of their data. Vector line layer.	95% Confidence the accuracy is between 0.5 and 2.0 Meters	Used in analysis for locational information and road network references

3.1.2. Collision Factor Data Layer

While several variables were identified through the literature review as motorcycle collision factors, only one variable was evaluated within this study as it has a direct connection to a possible mitigation measure. Traffic Flow (TF) was evaluated because of the connection between higher AADT values and the success of the introduction of a motorcycle lane. This layer was made accessible to the public as shapefiles through the Kentucky Transportation Cabinet's (KYTC) Datamart website. The Traffic Flow layer being used within this project contains base road attribution (road name, mile points, unique identifiers) and attributes specific to traffic flow: Average Annual Daily Traffic (AADT), count (LASTCNT), and the year that count was conducted in (LASTCNTYR).

The Rating Evaluation Section (EV) was used as a factor to determine viable route segments that can support the addition of a motorcycle lane to the existing infrastructure. This dataset, also provided as a shapefile to the public by KYTC, contains roadway attributes including the widening potential of roadways (WIDENFEAS) and potential widening obstacles (WIDENOBST). Refer to Table 2 for additional information on the crash factor layers to be used within this project.

Table 2. Collision factor layers

Dataset	Source	Scale	Precision	Accuracy	Purpose
Average Annual Daily Traffic (AADT) (TF)	KYTC through DataMart	NAD 1983 StatePlane Kentucky FIPS 1600 Feet	KYTC maintains data collection standards for road centerlines and associated attributes to help increase the precision of their data. Vector line layer.	95% Confidence the accuracy is between 0.5 and 2.0 Meters	Identified crash factor – used for analysis
Rating Evaluation Section (EV)	KYTC through Datamart	NAD 1983 StatePlane Kentucky FIPS 1600 Feet	KYTC maintains data collection standards for road centerlines and associated attributes to help increase the precision of their data. Vector line layer.	95% Confidence the accuracy is between 0.5 and 2.0 Meters	This dataset contains attributes for widening potential which will help determine areas which can support the addition of a motorcycle lane

3.1.3. Recorded Crash Layer

Motorcycle crash locations spanning ten consecutive years within Kentucky were evaluated as a variable in order to determine hot spots of collision activity. Kentucky State Police (2019) (KSP) provides collision information for all vehicle types through a Kentucky Collision Analysis website. The website is designed to let the public create a query and access resulting crash records. For this project, crash records were queried using motorcycles as a vehicle type and crash dates between January 1, 2009 to December 31, 2018. A ten-year period was selected

Table 3. Recorded collision data

Dataset	Source	Scale	Precision	Accuracy	Purpose
Crash Locations	KSP	Layer was created using WGS 84 and then projected to NAD 1983 StatePlane Kentucky FIPS 1600 Feet	Records accessed through excel sheet download. A vector point layer was created	Unknown – records accessed through excel sheet download	Core analysis data layer – Contains location of collision and collision attributes

to account for fluctuations between years due to factors such as weather. This information was returned in an excel table format and was then imported into ArcPro as a table. The resulting table was used to make a point layer with the latitude and longitude attribution inherent in the excel download. Additional attribution included with the crash data is the county, roadway, mile point, collision date and time, number of vehicles involved, number of persons injured, number of persons killed, roadway condition, weather, collision manner, roadway characteristics, light conditions, and factors involved. Supplementary information on the recorded crash layer can be viewed in Table 3 below.

3.2. Research Design

To support the project objective, the data above was analyzed and compared using the Environmental Systems Research Institute's (Esri) ArcGIS Pro program. Figure 14, referenced below, is a graphical representation of the overall workflow used in completing this project's objective. There were four overarching phases for this project: (1) configure layers and map document, (2) analyze crash location layer using the Optimized Hot spot Analysis tool, (3) identify suitable roadway segments based on state maintained roads, AADT, and widening feasibility, and (4) summarize the viable locations which can sustain a motorcycle lane.

3.2.1. Configure Layers and Map Document

The first step in this project was to gather data identified through the literature review as relevant to motorcycle crash factors, gather layers related to jurisdictional and base transportation, and gather motorcycle collision data for the specified ten-year period. These layers were then added to an ArcGIS Pro document and grouped based on their role in the

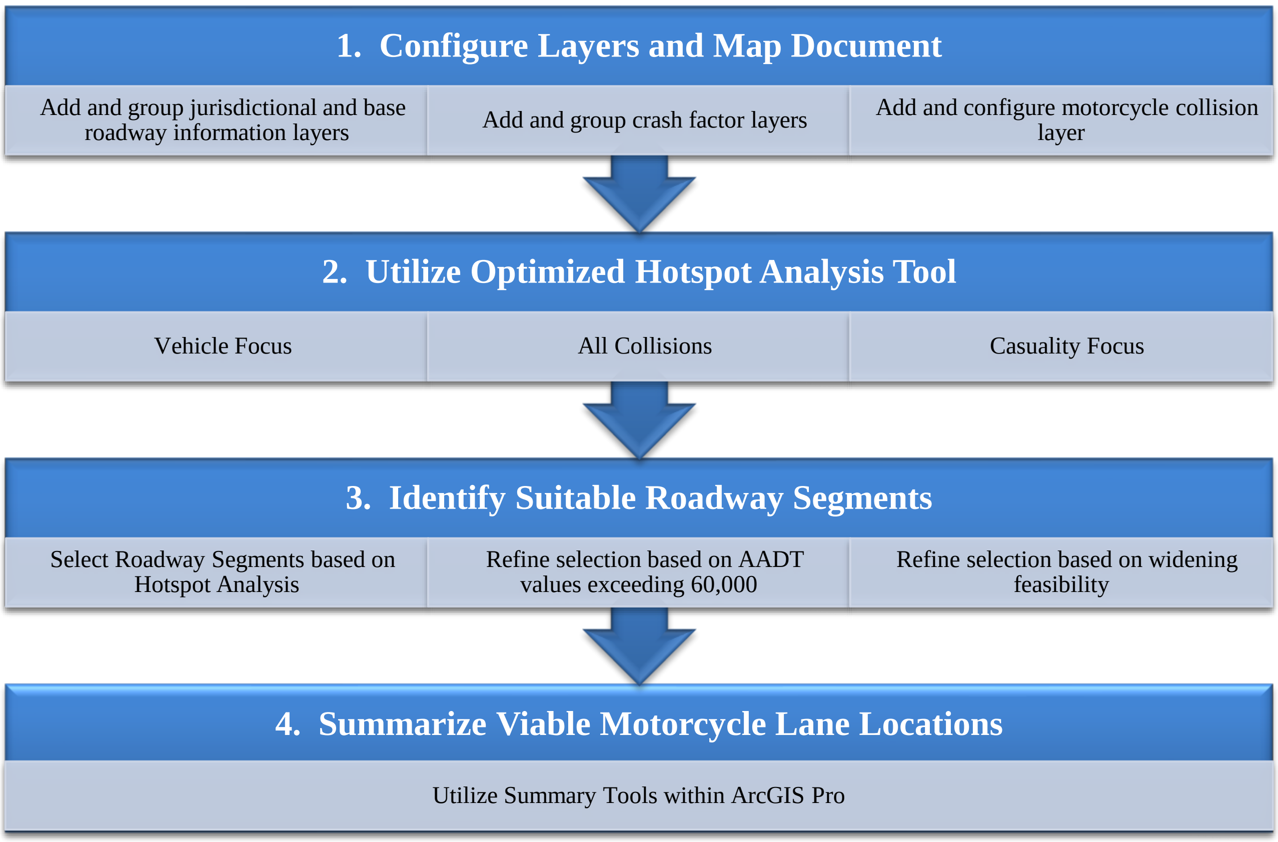


Figure 14. Methods outline

research as either jurisdictional / base information, collision factors, or collision data. ArcGIS Pro was selected as the mapping program to use for various reasons. This project required multiple map frames for each of the study areas, multiple layouts for exporting the map frames, the ability to run processes efficiently, and the infrastructure to retain the history of all processes or tools run. ArcGIS Pro, as an operating platform, was able to satisfy all the requirements above while also having the benefit of an intuitive user interface and the ability to access and use Esri basemaps. ArcGIS Pro also stores its files in the form of projects, helping organize the products used and created while completing the technical work. Additional mapping programs such as QGIS or ArcMap satisfied some of the requirements listed above but not all of them; it is because of this ArcGIS Pro was selected for use in satisfying the objectives of this project.

Once the shapefiles and table were imported to ArcGIS Pro, the shapefiles were symbolized based on their attribute (i.e. route type, AADT level) to facilitate the visual interpretation of the layers. The collisions records, imported as an excel table, were turned into a point layer based on the X (Longitude) and Y (Latitude) attributes via the XY Table to Point tool. Upon layer creation, the projection was set to WGS 1984 for this layer and then projected to match the projection for the rest of the layers as NAD 1983 StatePlane Kentucky FIPS 1600 Feet.

This collision layer was then copied six times into the same map frame, allowing for distinct queries to be applied to each copy of the master collision layer for the state. Refer to Appendix A for a complete listing of all queries used per study area. These queried layers were categorized into three groups: a master layer with all records, vehicle status layers, and injury status layers. The vehicle status group contained three queried layers: motorcycle only collisions, motorcycle and one vehicle collisions, and motorcycle and multiple vehicle collisions. The injury status group contained three layers as well: no casualty collisions, collisions involving one or more fatalities, and collisions involving one or more injuries (but no fatalities). Refer to Figure

15 for an example of the resulting table of content with all layers in their respective groups and the selected symbology.

The decision was made to use different subsets of data for running the Optimized Hot spot Analysis tool for two main reasons. First, the information and practices uncovered in the

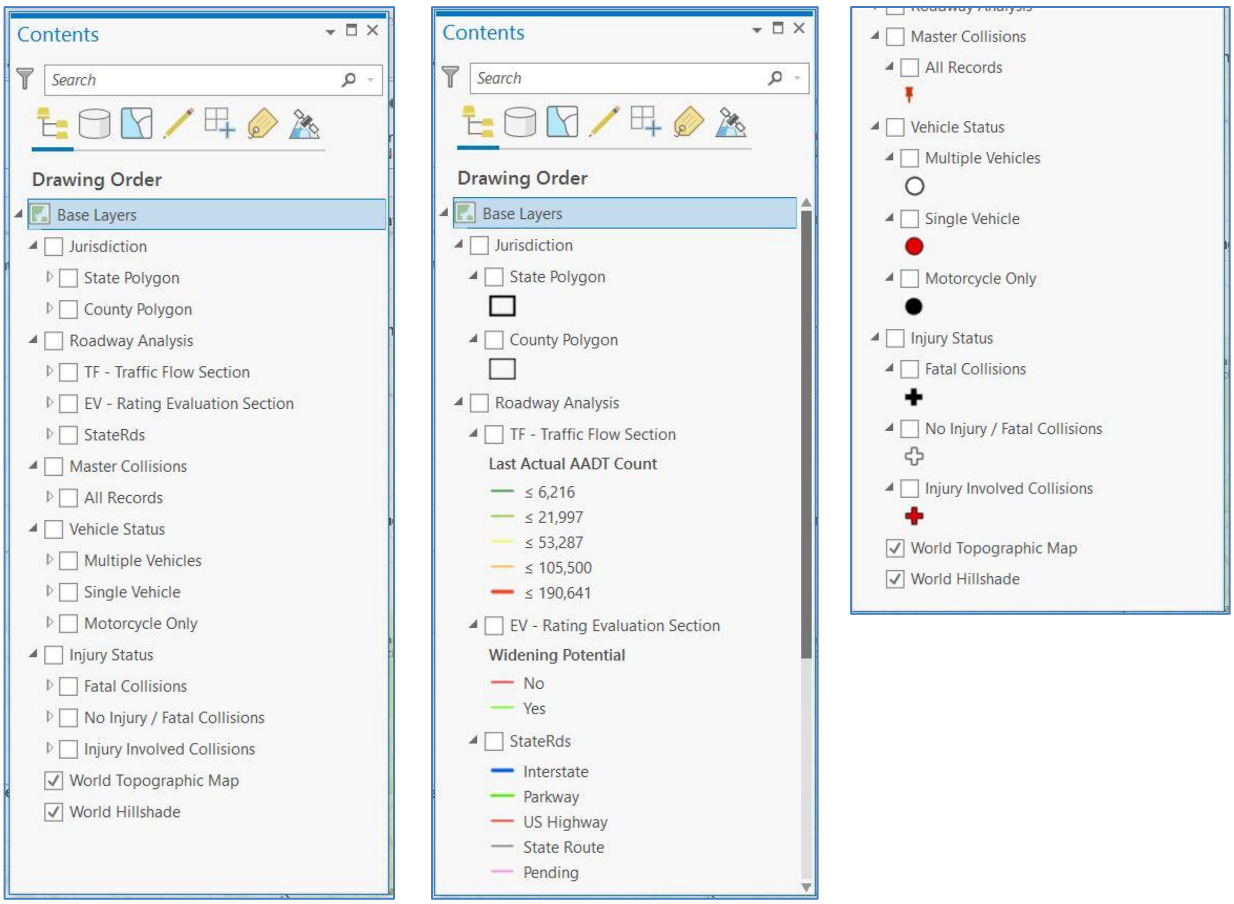


Figure 15. Layers and symbology

literature review suggested different levels of factor involvement and severity can be determined on the manner of the collision. For instance, higher levels of injury are found to result from a road design issue (Allen 2017, 165), suggesting the road design in hot spots found for collisions involving injuries or fatalities may have played a factor in the collision. The identification of hot spots relating to injury severity can alert transportation agencies of a potential need to evaluate the road design in that area. The vehicle involvement in a motorcycle collision can also assist in determining the best mitigation strategies for reducing motorcycle involved collisions in an area (Schneider 2012, 669). Different factors can contribute to the manner of motorcycle only, motorcycle and one vehicle, and motorcycle and multiple vehicle collisions – completing the hot spot analysis on these subsets of the collision records increases the potential of the results to be utilized in an efficient and appropriate manner.

Creating subsets of the collision records also allowed for identifying hot spots which may not have been identified as statistically significant otherwise. Using subsets allowed the analysis to identify hot spots relating to collision severity and vehicle involvement that would not have been visible in a hot spot analysis of all motorcycle involved collisions. For instance, hot spots were identified for fatality involved collisions differing from hot spots for causality free (no fatality or injury) collisions – this would not have been possible if the collision records were evaluated as a complete set with all records. The potential implications of this varied hot spot analysis are further discussed in the Conclusion section of this document.

Once all layers were queried appropriately, symbolized, and grouped, map frames were made specific to the different study areas (Jefferson County, Fayette County, Meade County, and Livingston County) and the base data layers and groups were copied to the new map frames. The queries applied on the base data frame (specific to the entire state of Kentucky) were then modified for the appropriate county, allowing for a focused data view specific to that study area. Layouts (formatted map views with components including titles, legends, scales, etc…) were then created for every map frame to facilitate the sharing and preserving of results from the analysis and technical work.

3.2.2. Utilize Optimized Hot Spot Analysis Tool

The second overarching category of work within this research methodology was to analyze the collision subsets. The Optimized Hot Spot Analysis (OHSA) tool was chosen to be used on each of the collision subsets to support one of the projects objectives of identifying areas that could benefit from the introduction of a motorcycle lane by identifying areas with statistically significant clusters of motorcycle involved collisions. The OHSA tool uses the Getis-Ord Gi statistic to analyze records within the input layer (i.e. the motorcycle collisions) to determine if there are statistically significant clusters (Esri 2019). Statistically significant clusters indicate the possibility of collision occurrences which are not random and may be the result of factors present within that location.

The Optimized Hotspot Analysis tool or the Getis-Ord GI Statistic has been used in multiple case studies to determine areas of statistical significance for different phenomena. For instance, the tool was used to determine hot and cold spots for power outages within certain cities in California (Sultan et al. 2016, 229). Further analysis was then completed by researchers on the identified areas of statistical significance to evaluate the age of infrastructure as a factor in outages. The Getis-Ord GI statistic was also used in identifying traffic accident hot spots for Brunei Darussalam, a country in South East Asia (Zahranel-Said et al. 2019, 1). The Getis-Ord GI statistic allows researchers to evaluate the occurrence or frequency of widespread phenomena, such as power outages, crime or accidents. The tool is used strictly for frequency, however, and cannot take into account severity (unless the data is already queried or formatted to account for severity). Within this project, areas of statistical significance were identified using the Getis-Ord GI Statistic and then those areas were further evaluated for the presence of factors relating to motorcycle-involved collisions.

The tool creates an output layer with several attributes representing the level of statistical significance for each cell of analysis: the Gi_Bin, z-score and p-value. The Gi_Bin is the field representing the percentage of statistical significance (3 = 99% Confidence, 2 = 95% Confidence, 1 = 90% Confidence, and 0 = no statistical significance) (Esri 2019). The z-score value for the record indicates the amount standard deviations the cell is away from being considered random. A value of 1.65 indicates the cell has reached the 90% confidence level, a value of 1.96 indicates a 95% confidence level, and a value of 2.58 or greater indicates at least a 99% confidence level of the cell not being spatially random (Law and Collins 2016, 323). While the z-score represents the standard deviations for a cell, the p-value records the probability of the records within a cell being random. A value of 0.1 indicates the cell has reached the 90% confidence level, a value of 0.05 indicates a 95% confidence level, and a value 0.01or smaller indicates at least a 99% confidence level of the cell not being spatially random – the closer the value is to one, the higher the probability the records are spatially random (Law and Collins 2016, 324).

The Optimized Hot Spot Analysis tool requires several parameters be set before it can run on the input dataset and it allows for certain parameters to be modified from the default. For this project, the parameters were set consistently for all study areas and motorcycle collision subsets. Prior to running the tool, a file geodatabase was created within the ArcGIS Pro Project folder to house all resulting layers from the analysis. The tool was then populated by defining the input layer, specifying the output layer name and location within the file geodatabase, setting the aggregation method to the "Count incidents within fishnet grid" selection, selecting the queried county layer specific to the study area, and overriding the cell size following a 5000 meter, 500 meter, 250 meter, and 100 meter scale for each run of the tool (the tool was run multiple times on each layer for the various cell sizes). Figure 16 displays the tool parameters for the Fayette County master collision layer at a 250 meter cell size. It is important to note that while the OHSA tool was utilized for every motorcycle collision subset layer, all cell sizes were not attempted for every layer – this will be explained further within the Results section of this document. Refer to Appendix B for a table containing the layers and which cell sizes were attempted through the OHSA tool.

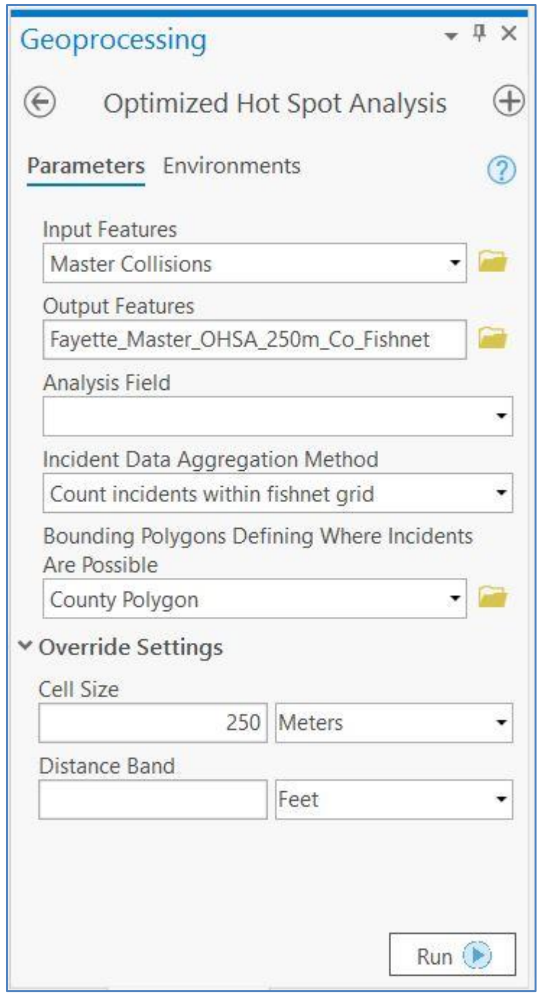


Figure 16. OHSA example

3.2.3. Identify Suitable Roadway Segments

Once the OHSA tool was completed for the motorcycle collision subsets for every study area, roadway segments suitable to the introduction of a motorcycle lane with statistically significant clusters of motorcycle involved collisions were identified. This third overarching category of work within the research methodology was completed by using various tools and queries. The purpose was to identify locations with statistically significant collision clustering on roadways adhering to the following parameters:

(1) the route must be a state-maintained road

(2) Average Annual Daily Traffic (AADT) value of at least 60,000

(3) existing infrastructure capable of being widened to support a motorcycle lane

The original intention was to evaluate each subset of motorcycle collision hot spot results by using the union tool to combine the hot spot layers into a single hot spot record per subset of vehicle involvement and injury status for the specific study area. The hot spot layers for motorcycle only, motorcycle with one vehicle, and motorcycle with multiple vehicles would have been combined to a single hot spot layer on the vehicle involvement. Similarly, the hot spot layers for no causality, fatality involved, and injuries without fatalities would have been used within the Union tool to create a single hot spot area representing the injury status of collisions. A uniform cell size could not be used on all layers for the OHSA, however, and this planned route of analysis could not be completed. The master collision layer for each study area was used for identifying suitable roadway segments and that process is outlined below.

The queries were set first for each study area to ensure the parameters above were met and factored in for the analysis to determine site suitability. Queries were set on the resulting OHSA layers to filter for cells with 90% confidence of statistical significance using the Gi_Bin attribute (values not equal to 0). Queries were then set on the Traffic Flow (TF) layer for a LASTCNT value equal to or greater than 60,000, and the Rating Evaluation Section (EV) layer for a D_WIDENFEA value not equal to "No widening is feasible." Once these queries were set, Esri geoprocessing tools were used to identify roads with the above attributes.

The Clip Layer tool was used first to determine if any of the identified hot spots were located on a state-maintained roadway. The input layer was the state roads layer queried for the specific study area. The clip layer used for the tool for each study area was a viable and complete OHSA layer for all collisions within the study area – this will be discussed in greater detail within the Results section. The output for the tool was saved within the file geodatabase for the project. Refer to Figure 17 for an example of this process in Jefferson County. The output from this tool was then added to a new group within the map frame titled Results and the symbology was adjusted to be a green line of width 4 pts. This specification was decided on because it made the output easily identifiable when viewed with other layers on the map.

It is important to note the Traffic Flow layer and the Rating Evaluation Section layer used within this project were collected by KYTC on state-maintained roads. These two layers were intentionally being used because they are factors in determining the site suitability of a potential motorcycle lane. Consequently, the roads being evaluated within the scope of this project for their capacity to house an additional lane exclusively for motorcycles are only state maintained roads. Motorcycle collision records were included within the project regardless of occurring on a state or locally maintained road to ensure the hot spots identified through technical analysis were statistically significant and indicative of areas sincerely needing infrastructure improvements for improving motorcycle safety.

After a successful completion for the Clip Layer tool, the Clip tool was used to determine if any state-maintained roads within the OHSA layer also had an AADT value equal to or exceeding 60,000. The input for this tool was the output from the Clip Layer tool and the clip features were the Traffic Flow layer specific to the study area (refer to Figure 18 for an example of this tool being applied to Jefferson County). Upon a successful completion of this tool, the layer was added to the Results layer group and the symbology was updated to a yellow line of width 2.5 pts. This allowed for stacking of the tool outputs, allowing the user to view the difference in viable routes based on AADT. The final tool used in the analysis was another clip tool. The output from the last tool was used as the input for this tool and the final clipping features were the Rating Evaluation Section (refer to Figure 19 for an example of this tool being applied to Jefferson County). This final step allowed for the identification of state-maintained

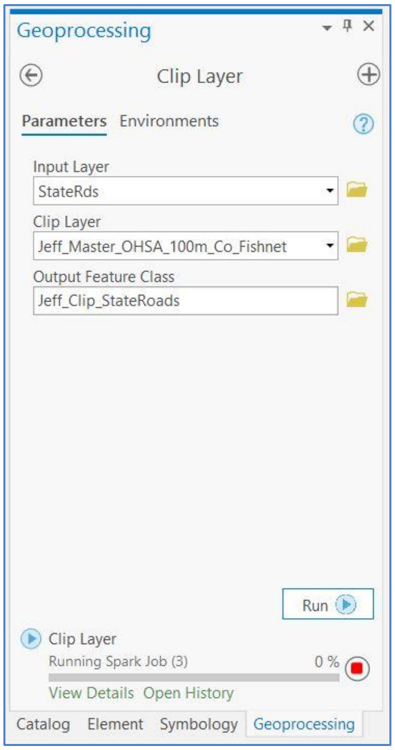


Figure 17. Clip layer tool

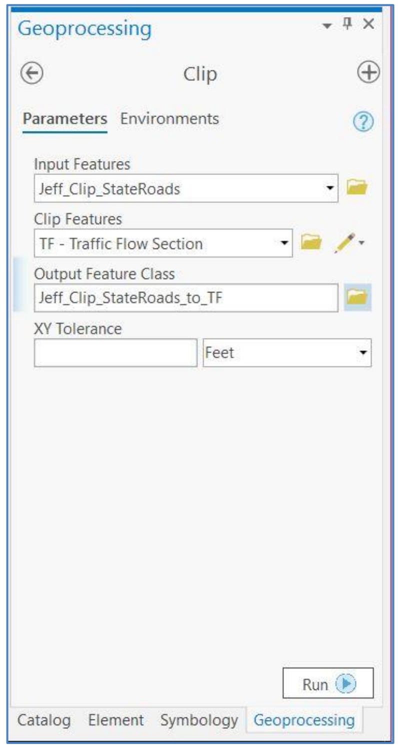


Figure 18. Clip for AADT

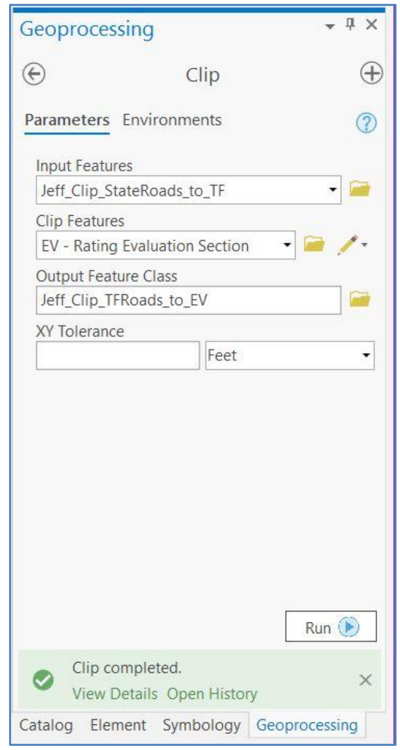


Figure 19. Clip for widening

roads within an identified hot spot with an AADT value exceeding 60,000 and the potential to have an additional lane exclusive to motorcycles added.

3.2.4. Summarize Viable Motorcycle Lane Locations

The fourth and final overarching category of work within this research methodology was to create a summary table from the final output of viable locations, allowing for the information to be shared with key stakeholders as a summary report of findings for the study area. The Esri Summary Statistics tool was used to accomplish this task, allowing for the creation of a table specifying the different routes determined through analysis to be a viable location as well as the count for how many times that route was identified and the total length of roadway directly within the hot spot. The final layer was used as the input for the tool and attributes within the layer were selected with the summary information needed. This summation table was added to the final layouts for the study area. Refer to Figure 20 for an example of the summary statistic table created for Jefferson County.

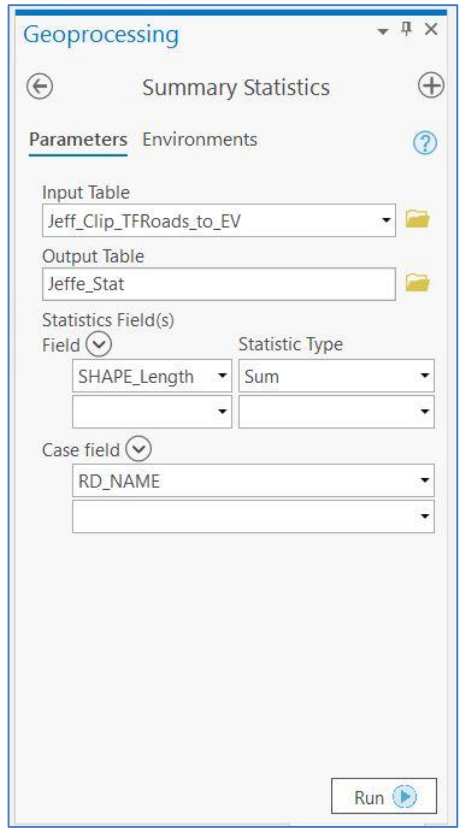


Figure 20. Summary statistics

Chapter 4 Results

The methodology outlined in Chapter 3 was completed for each of the study areas although the entire methodology could not be completed on Livingston and Meade counties because motorcycle lane parameters could not be met by the county infrastructure and need. The motorcycle-involved collision hot spots, state-maintained roadways, Average Annual Daily Traffic (AADT), and lane widening potential were analyzed for each study area and if a county did not have locations which could satisfy the parameters outlined in Chapter 3, the analysis was ended inconclusively. Appendix C contains a table referencing the results for the complete analysis on each study area. Locations with the need and infrastructure for the addition of an exclusive motorcycle lane were only able to be identified within Fayette and Jefferson County.

4.1. Livingston County Results

Throughout the technical work it was discovered Livingston County did not meet all parameters for determining the site suitability of a motorcycle lane. The county does not have locations where the AADT exceeded 60,000 within identified hot spots and consequently was not evaluated on the infrastructure element of widening feasibility. The need for a motorcycle lane could not be justified.

The Optimized Hot Spot Analysis tool was successfully completed on the master collision layer for the county as well as the queried layers representing motorcycle only involved collisions and injury only involved collisions. The cell sizes used, results, and any errors received can be seen within Table 4. Multiple hot spots were found within the county for the different subsets and the master layer for motorcycle involved collisions (refer to Appendix D for maps of the varying hot spots). State-maintained roads within the hot spot areas were identified (refer to Figure 21) using the Clip Layer tool as the methodology outlined but the following step of using the Clip tool to determine which of those routes had an AADT value equal to or greater than 60,000 yielded no results and the analysis was concluded for Livingston County (Table 4).

Table 4. Livingston County results

Study Area	Focus Area	# of Record	100m	250m	500m	5000m	**Z m	OHSA Results	Final Results
Livingston County, KY	Multiple Vehicles	1	NC	NC	NC	NC	NC	*Failed	No viable locations identified - county does not contain state-maintained roads meeting or exceeding 60,000 AADT intersecting the identified hot spots.
	Single Vehicle	17	NC	NC	NC	NC	NC	*Failed	
	Motorcycle Only	39	NC	NC	CV	NC	CI	Complete	
	No Casualty	10	NC	NC	NC	NC	NC	*Failed	
	Fatality Greater than or equal to 1	1	NC	NC	NC	NC	NC	*Failed	
	Injury greater than or equal to 1	46	NC	NC	CV	NC	CI	Complete	
	All County Collisions	57	NC	NC	CV	NC	CI	Complete	

CV	Completed, Viable Result
NC	Not Completed
CI	Completed, Inconclusive

*Esri generated error code (001570) signifying the layer did not have the minimum requirement of 30 records and the OHSA Tool failed

** Tool was completed using automatically generated cell size

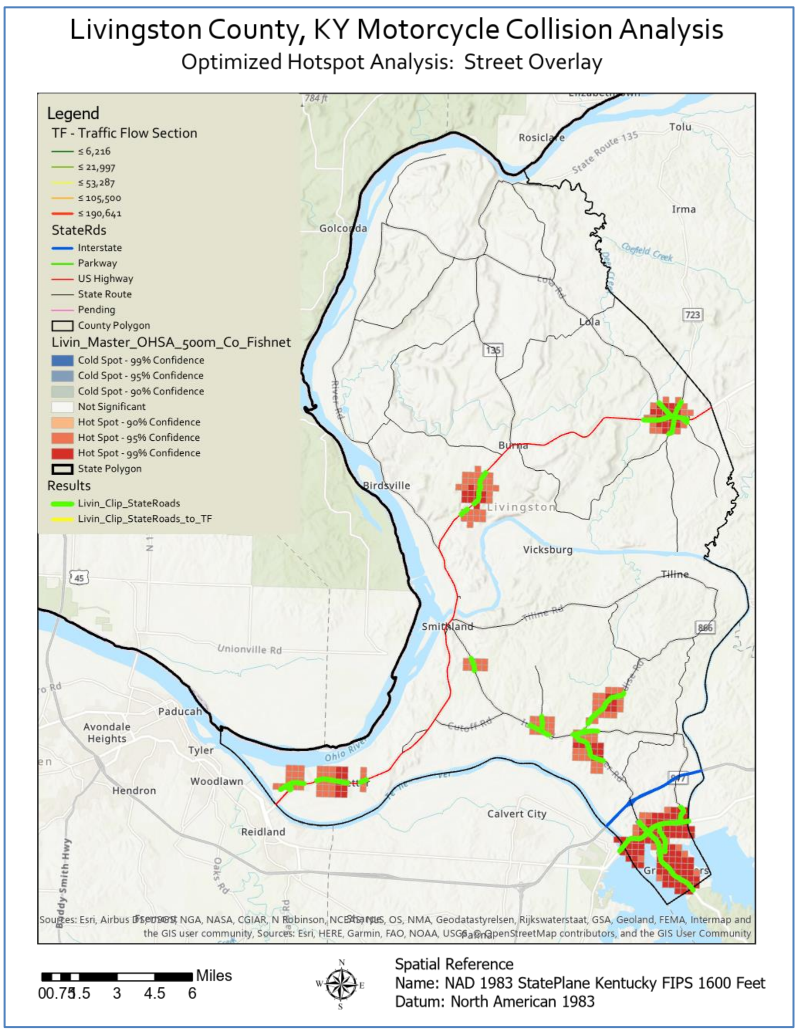


Figure 21. Livingston County final analysis

4.2. Meade County Results

Meade County did not meet the parameters for determining the site suitability of a motorcycle lane as the county does not have any state-maintained routes with an AADT at or exceeding 60,000. Within this project, motorcycle lanes are viewed as a potential mitigation measure to increase motorcyclist safety for areas with traffic volumes high enough to warrant them. Similar to Livingston County, Meade County was evaluated for hot spots, their location on state-maintained roads, and then the AADT values were checked. Once it was determined, the AADT parameter could not be met, the analysis stopped, and the infrastructure element of widening feasibility was not evaluated. The need for a motorcycle lane could not be justified despite hot spots being successfully identified.

The Optimized Hot Spot Analysis tool successfully completed for the Meade County master collision layer and the queried layers for a motorcycle and single vehicle collision, motorcycle-only involved collisions, and injury only involved collisions. Similar to Livingston County, varying cell sizes were used to gain successful completions of the OHSA tool. The cell sizes used, results and any errors received can be seen within Table 5 (refer to Appendix E for maps of the varying hot spots). The state-maintained roads within the county were successfully identified (refer to Figure 22) using the Clip Layer tool but the state-maintained roads within

Table 5. Meade County results

Study Area	Focus Area	# of Record	100m	250m	500m	5000m	**Z m	OHSA Results	Final Results
Meade County, KY	Multiple Vehicles	3	NC	NC	NC	NC	NC	*Failed	No viable locations identified - county does not contain state-maintained roads meeting or exceeding 60,000 AADT.
	Single Vehicle	44	NC	CV	CI	NC	NC	Complete	
	Motorcycle Only	61	NC	NC	CV	NC	NC	Complete	
	No Casualty	25	NC	NC	NC	NC	NC	*Failed	
	Fatality Greater than or equal to 1	16	NC	NC	NC	NC	NC	*Failed	
	Injury greater than or equal to 1	71	NC	NC	CV	NC	NC	Complete	
	All County Collisions	108	CI	CI	CV	NC	NC	Complete	

CV	Completed, Viable Result
NC	Not Completed
CI	Completed, Inconclusive

*Esri generated error code (001570) signifying the layer did not have the minimum requirement of 30 records and the OHSA Tool failed

** Tool was completed using automatically generated cell size

Meade County all have AADT values lower than the 60,000 needed for analysis and the analysis was inconclusive for determining the site suitability of a motorcycle lane.

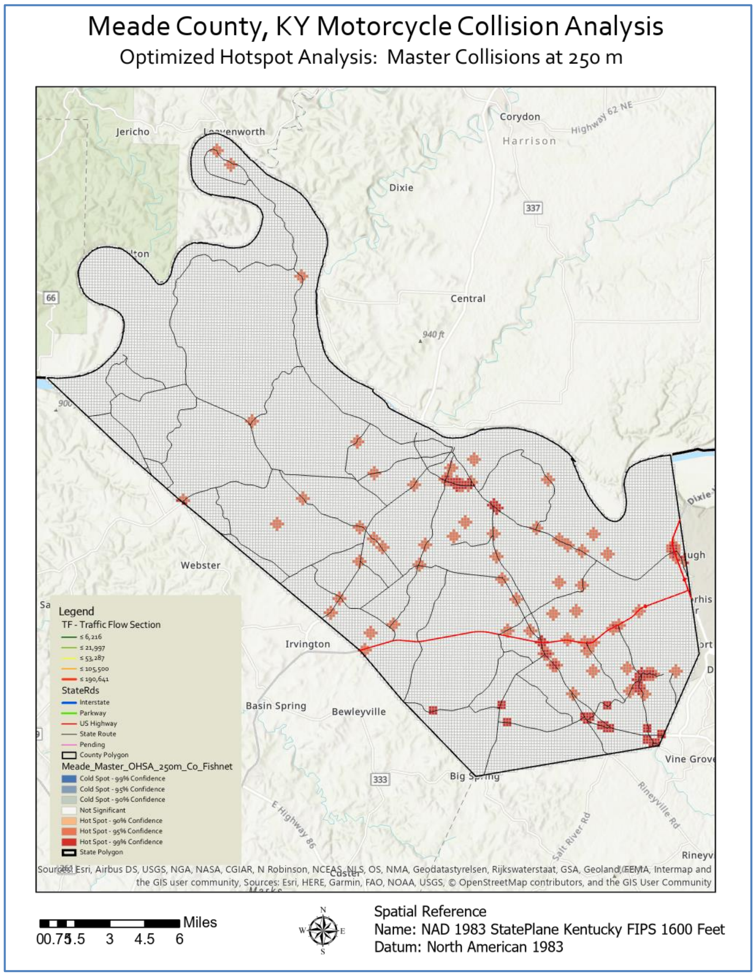


Figure 22. Meade County final analysis

4.3. Jefferson County Results

Jefferson County met all parameters for this study, and multiple locations were identified as viable sites for the introduction of a motorcycle lane. In following the methodology outlined in Chapter 3, hot spots were identified within the county for the master collision layer and suitable roadway segments were identified for locations meeting all parameters (state-maintained, AADT exceeding 60,000, with widening potential). Multiple sections of roadway met these parameters throughout Jefferson County and a summation table was created to capture the roadway name, number of sections, and overall length of the sections in feet (refer to Figure 23).

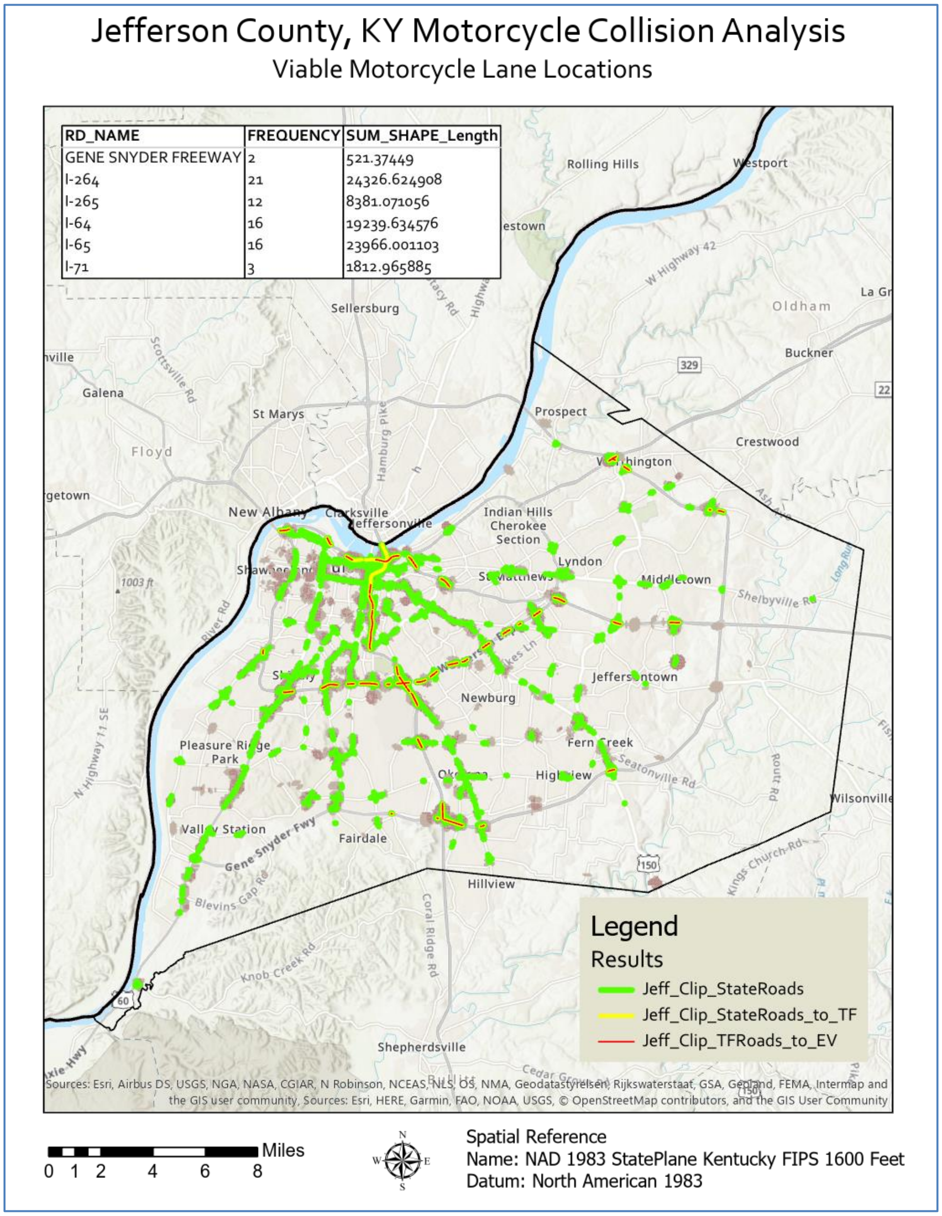


Figure 23. Jefferson County final analysis

Unlike Meade and Livingston counties, the Optimized Hotspot Analysis tool was able to successfully complete for the master collision layer and every subset of records. The resulting maps can be viewed within Appendix F, and Table 6 contains the results and cell size for each of the layers. The hot spot layer produced from the master collisions dataset for Jefferson County was used for identifying suitable roadway segments. The Clip Layer tool was used to select the state-maintained roadways within the statistically significant areas and the AADT value of 60,000 was used to further clip the roadway segments. The widening feasibility was evaluated and 70 roadway segments were identified, predominantly on I-264, I-64, and I-65. All aspects of analysis outlined within the methods chapter were successfully used for the Jefferson County study area and areas with need and the infrastructure to support a motorcycle lane were identified.

Table 6. Jefferson County results

Study Area	Focus Area	# of Records	100m	250m	500m	5000m	**Z m	OHSA Results	Final Results
Jefferson County, KY	Multiple Vehicles	157	CI	CV	CV	NC	CI	Complete	Multiple locations with need and infrastructure capable of supporting a motorcycle lane identified.
	Single Vehicle	2099	CI	CV	CI	NC	CI	Complete	
	Motorcycle Only	904	CV	CI	CI	NC	CI	Complete	
	No Casualty	1109	NC	CV	NC	NC	CI	Complete	
	Fatality Greater than or equal to 1	141	NC	CV	CV	NC	CI	Complete	
	Injury greater than or equal to 1	1951	CV	CI	NC	NC	CI	Complete	
	All County Collisions	3160	CV	CI	CI	NC	CI	Complete	

CV	Completed, Viable Result
NC	Not Completed
CI	Completed, Inconclusive

*Esri generated error code (001570) signifying the layer did not have the minimum requirement of 30 records and the OHSA Tool failed

** Tool was completed using automatically generated cell size

4.4. Fayette County Results

The Fayette County study area also met all parameters, and the outlined methodology was utilized to successfully identify sites with the need and infrastructure to support the addition of a motorcycle lane. The master collision layer for Fayette County was used in identifying suitable roadway segments meeting the parameters as state-maintained, having an AADT value at or exceeding 60,000, and having the potential to be widened. Similar to Jefferson County, Fayette County had multiple sections of roadway meet the parameters above. These segments were summarized by road name, the number of occurrences, and the total length of the segments in feet (refer to Figure 24).

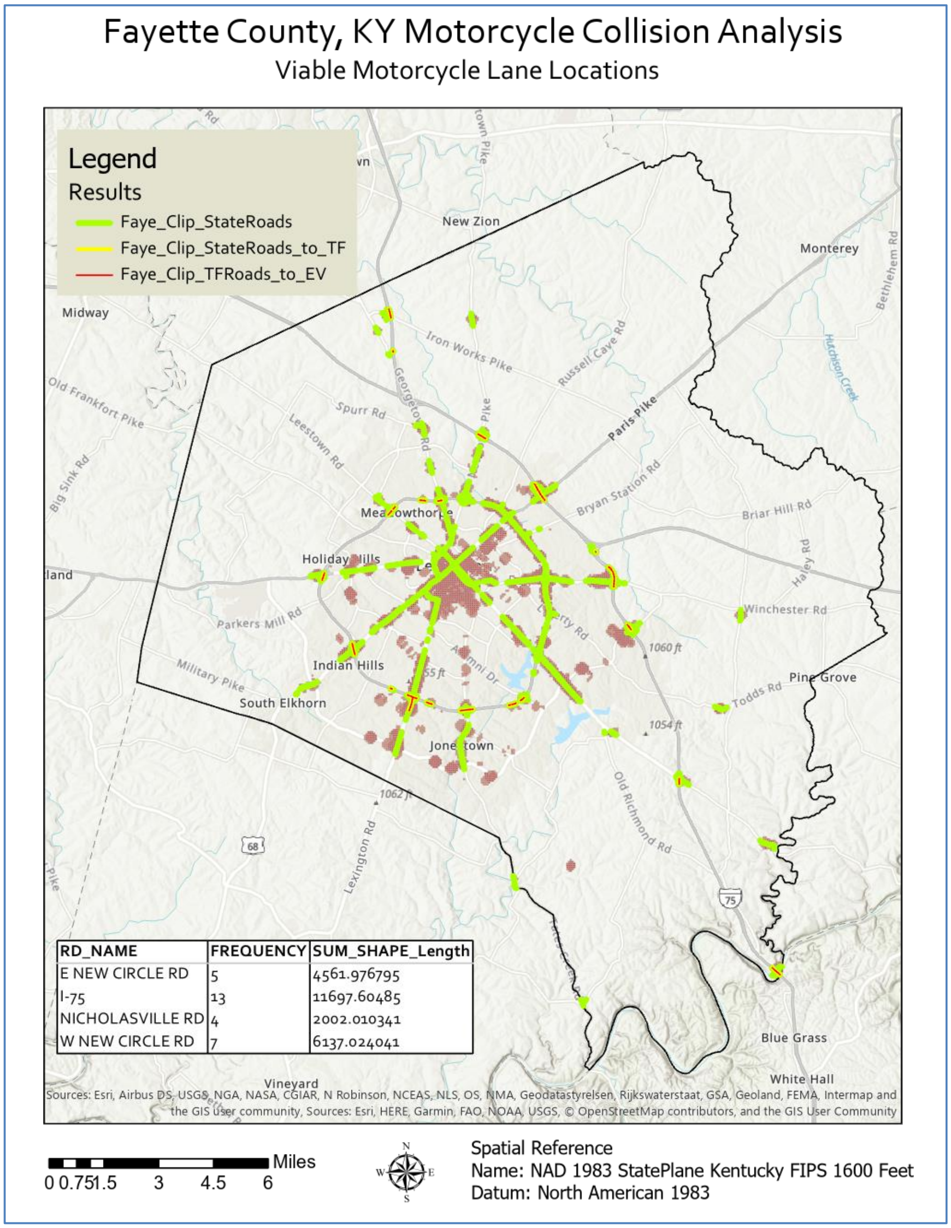


Figure 24. Fayette County final analysis

The Optimized Hotspot Analysis tool was able to successfully complete the master collision and all collision subsets for the Fayette County study area. The resulting maps can be viewed within Appendix G and Table 7 contains the OHSA metrics and the final result. Parallel to the other study areas, differences in cell size for the OHSA tool led to the master collision OHSA output being used. The remainder of the analysis steps were completed and 29 roadway segments were identified throughout Fayette County. Interstate 75 had the highest occurrence within the results and the highest cumulative length of viable segments. The potential need (areas of statistical significance and AADT at or exceeding 60,000) and infrastructure to support the implementation of motorcycle lanes were validated with the analysis for Fayette County.

Table 7. Fayette County results

Study Area	Focus Area	# of Records	100m	250m	500m	5000m	**Z m	OHSA Results	Final Results
Fayette County, KY	Multiple Vehicles	50	NC	CI	CV	NC	CI	Complete	Multiple locations with need and infrastructure capable of supporting a motorcycle lane identified.
	Single Vehicle	837	NC	CV	NC	NC	CI	Complete	
	Motorcycle Only	384	NC	CV	NC	NC	CI	Complete	
	No Casualty	506	NC	CV	CI	NC	CI	Complete	
	Fatality Greater than or equal to 1	36	NC	CI	CI	NC	CI	Complete	
	Injury greater than or equal to 1	735	NC	CV	NC	NC	CI	Complete	
	All County Collisions	1271	CV	CI	CI	NC	CI	Complete	

CV	Completed, Viable Result
NC	Not Completed
CI	Completed, Inconclusive

*Esri generated error code (001570) signifying the layer did not have the minimum requirement of 30 records and the OHSA Tool failed

** Tool was completed using automatically generated cell size

It is important to note Fayette County was not included within the original scope of this project. The county was added as a study area once inconclusive results were found in both Livingston and Meade County. The initial analysis showed Fayette County as a potential study area that would lend to complete results because of the volume of recorded collisions within the county – Fayette County had the second-highest count for cumulative collisions, fatalities, and injuries. In an effort to apply the complete methodology to a second study area, the county was added to the project.

Chapter 5 Conclusion

The objective of this project was to create a reproducible methodology and successfully use GIS as a tool in determining the site suitability of motorcycle lanes within Kentucky to help increase motorcycle safety and save lives. This objective was met, and viable motorcycle lane locations were identified with a methodology that used multiple tools within ArcGIS Pro for hot spot analysis, querying, clipping, and summarizing. The study areas of Fayette County and Jefferson County, Kentucky, produced viable locations while the study areas of Meade County and Livingston County produced inconclusive results relating to traffic flow volumes. The gap identified within the literature review was also addressed within this process. A connection was made between identified factors and viable mitigation measures which could act as a solution to addressing the identified hazard. The methodology followed within this project provides a framework for further evaluation of factors identified as impacting motorcycle involved collisions and viable mitigation measures which could reduce the factor's impact. The methodology allows future work to continue closing the gap identified within the literature review of this project.

Although the Livingston and Fayette results were inconclusive, they were not unforeseen. Motorcycle lanes, as described within the related work chapter of this document, are viable solutions in areas where there are high volumes of motorcyclists and high volumes of traffic. Meade and Livingston County are not as populated as Jefferson and Fayette counties; they also have lower average AADT values, and the cost of modifying the existing infrastructure to create a motorcycle lane may not be justified because the population is not there to use it. Alternative solutions, including widening the lane or having targeted motorcycle safety campaigns, may be more feasible if the collisions are related to traffic flow or inattention of other drivers. Increasing the lane width has been shown to decrease the severe injury risk by over 27 % (Rezapour 2019, 115) because motorcyclists then have a larger amount of room for maneuvers attempted in avoiding imminent collisions. Reviewing the lane-splitting legislation, as discussed in the related work chapter, in an area with higher collision rates may also be a viable alternative to changing the existing infrastructure of the roadway for the creation of a motorcycle lane.

5.1. Project Limitations

When discussing the limitations of the work completed for this project, it is important to differentiate between what was expected to be completed and what was not able to be completed. Throughout the analysis and technical work, several expectations or intentions were set: create a replicable process, utilize the collision subsets for a focused analysis, and evaluate multiple identified collision factors. All of these expectations were met in varying capacities, although they were not all met completely. Limitations are what kept the expectations from being met within the context of this section.

Several scope changes were made to allow for the project to be completed keeping consideration of researcher abilities and time constraints. The initial intention was to evaluate all roadways within Kentucky (state or locally maintained) because of the nature of collisions. Collisions occur regardless of road ownership, and reducing the type of roadways evaluated could lead to segments being missed in dire need of attention by transportation agencies. For this reason, the hot spot analysis was completed on all motorcycle involved collision records to ensure the hot spot analysis layer was a valid representation of the areas experiencing a statistically significant amount of collisions. The technical work for identifying suitable roadway segments, however, was restricted to state-maintained roadways because of data availability. The methodology for identifying suitable roadway segments can be applied to a roadway regardless of location of ownership.

On the subject of data availability, a further limitation to this project was the lack of recorded motorcycle AADT. The AADT values used within this project were for all motorized vehicles – it was not specific to motorcycles although motorcycle involved collisions were the only collisions evaluated. When looking at the nature of a motorcycle exclusive lane, there needs to be a population present to use the lane as a validation component for modifying the infrastructure. As mentioned before, motorcycle involved collisions were the only collisions evaluated in lieu of having motorcycle AADT but having a motorcycle specific AADT data layer would have facilitated demonstrating the need in an area for an exclusive motorcycle lane. Research in Florida on motorcycle involved collisions and modeling future collision locations has shown mixed results on the benefits of having motorcycle specific AADT - rural and urban arterials showed an improved prediction of motorcycle involved collisions when using motorcycle AADT but predictions on rural and urban freeways showed either negligible or reduced prediction abilities when using motorcycle AADT (Lyon et al. 2016, 114).

With regard to the methodology created for accomplishing this project's objective, the workflow is replicable, but it could not be completely automated because of variations specific to the data and study areas. The application of the methodology to multiple study areas helps validate the ability to apply it to locations outside of Kentucky and factor in different variables (i.e., using the percentage of curve for a roadway as opposed to the AADT value or widening potential). The complete process, however, cannot be replicated by a model without custom scripting. The first issue arose with the pixel size used in the Optimized Hot Spot Analysis tool. Trial and error were the methods used in selecting the "valid" and final hot spot layer. When running the tool without specifying a pixel size, the tool takes into account the record count and polygon study area to calculate a default pixel size and this default changes for every layer evaluated.

The varied pixel counts may not be an issue for some types of analysis, but when trying to select impacted roadways for collision counts, the pixel size needed to be smaller in every run of the model. An array of pixel sizes was selected for the study areas including 100m, 250m, and 500m and z (the default obtained by not entering a pixel size). Refer to Figure 25 and Figure 26 to see an example of Jefferson County with the default pixel size and the pixel size set at 250m. The OHSA tool would be used for each of the layers at those pixel values - unless a visual review of the resulting layer indicated the tool was making every record its own hot spot (refer to figure 27 to see this happening in Meade County – these are not actual hotspots, they are every point within the layer being evaluated). Study areas with a sufficient number of records to run

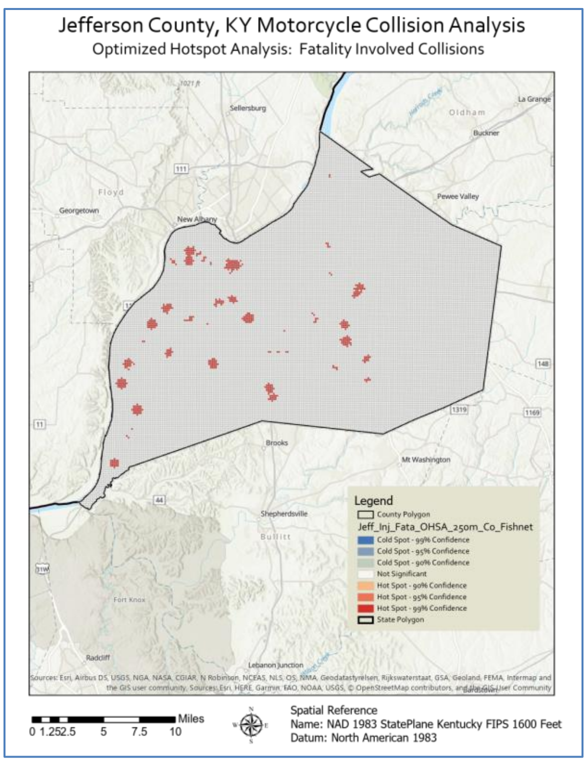


Figure 25. Jefferson County 250 m cell

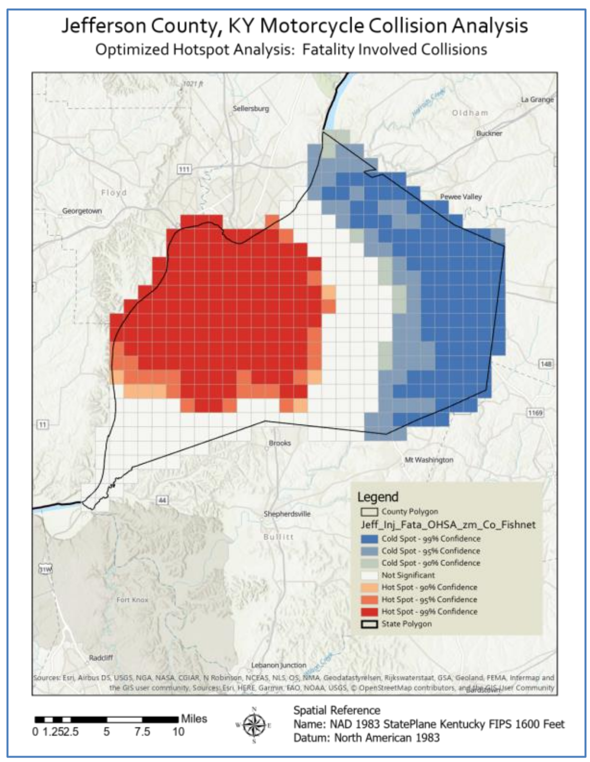


Figure 26. Jefferson County default cell

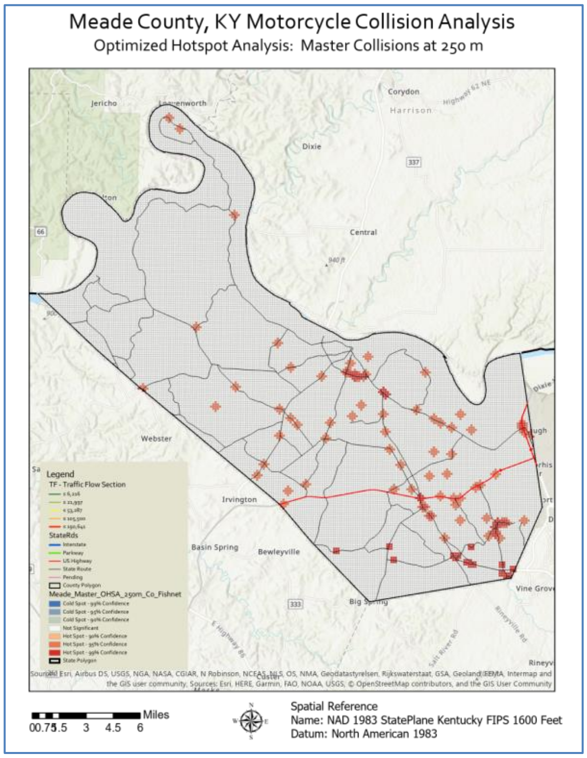


Figure 27. Meade County example

the OHSA tool but an insufficient amount to detect hot spots were producing OHSA output layers that incorrectly represented hot spots. A manual review of every OHSA was needed to determine if the selected pixel size was appropriate and this impacted the ability to replicate the methodology as a model for the OHSA portion. A potential model could be created using scripting languages such as Python to compare the number of identified hotspots with the number of records in the layer being evaluated but that solution could not be explored with the time constraints of this project. Additionally, several layers within Livingston and Meade county failed because they did not have the number of records required to run the OHSA tool (30 records) – this could also be accounted for within a custom script but it fell outside the scope of this project.

5.2. Future Work

The work completed within this project can be applied to different areas, for different mitigation measures, and with different collision factors. The steps within the methodology can be replicated for different study areas as long as the data layers used for this project have an equivalent layer for the new study area. It is important to clarify or reiterate this project evaluated state-maintained roadways for suitable locations to implement a motorcycle lane, using the relationship between higher traffic flow volumes with an increased probability of motorcycle involved collisions. The AADT data used within this project did not have a motorcycle-specific AADT value as the Kentucky Transportation Cabinet does not track that information – a future project could use an area's recorded motorcycle AADT if it is known to refine the suitable locations from those obtained through an all-vehicle AADT value. Future work for this project could also include evaluating additional collision factors including curve, slopes, speed limits, pavement roughness, etc. and adjusting the safety measure being evaluated to reflect the collision factor being evaluated. For instance, the collision factor of shoulder type (i.e. rumble strip, concrete, guardrail) could be evaluated to determine if the shoulder type in an area is contributing to the frequency or severity of an accident.

Future avenues this research could take also include the evaluation of motorcycle involved collisions at intersections and in areas with an increased truck AADT, and the integration of geodesign with results from the project. Focus for future work stemming from the results of this project could center on motorcycle involved collisions specifically near or at intersections. The existing infrastructure (signs) and line of sigh could also be evaluated to determine if infrastructure changes could reduce the occurrence of motorcycle involved collisions. This specific facet was not analyzed within this project because the project objective dealt with higher flow areas and the infrastructure change for a motorcycle lane but if an area had collision records, a layer of intersections or nodes, and the infrastructure surrounding intersections, similar analysis could be completed. Similar analysis could also be performed using semi-truck AADT to determine if motorcycle involved collisions occur more frequently in an area with a higher truck presence. This could potentially indicate line of sight limitations stemming from the size of semi-trucks as a semi-truck could impact the ability of other motorists to see a motorcyclist.

In this regard, the topic of geodesign could also be explored because the findings from these studies can be utilized in designing a road with geographic components in mind to address factors as they are identified. Geodesign – within the context of this paper – is an emerging area of work that unites the ability to plan, predict, and interact with geographic features in one focus (Ervin 2012). Using predictive models or analysis completed on existing data as a base and attempting to create solutions for phenomena being experienced (such as an increased occurrence of motorcycle involved collisions in a certain area) is a possible application of geodesign. In future work, the application of geodesign can be further explored in addressing identified hotspot locations with various factors present to create a solution which minimizes the impact of those factors within a geographic context.

Additional collision attributes could also be evaluated in future work revolving around increasing motorcycle safety. For instance, if age or rider experience is recorded with collision data, collision records could be evaluated to see if younger or inexperienced riders in a certain region have collisions on a more frequent basis. If this is the case, that area could be targeted by transportation agencies with a safety campaign for motorcycle classes aimed at increasing rider maneuvering ability and education. This project helped create a base with a working methodology that unites the existing identification of collision factors with the application of mitigation measures for increasing motorcycle safety. The potential future work revolving around GIS and increasing motorcycle safety is limited only by the data available and willingness to complete the project.

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Appendix A: Queries

Study Area	Motivation	Category	Focus Area	Definition Query
Kentucky	Statewide comparrison - acts as a control for the specific, county based	Vehicle Status	Multiple Vehicles	UnitsInvolved <> 1 Or UnitsInvolved <> 2
			Single Vehicle	UnitsInvolved = 2
			Motorcycle Only	UnitsInvolved = 1
		Injury Status	No Casualty	NumberKilled = 0 And NumberInjured = 0
			Fatality Greater than or equal to 1	NumberKilled <> 0
			Injury greater than or equal to 1	NumberInjured <> 0
		Master	All Collisions	
Meade County, KY	Higher percentage of motorcycle involved collisions resulting in	Vehicle Status	Multiple Vehicles	UnitsInvolved <> 1 And UnitsInvolved <> 2 And County = 'MEADE'
			Single Vehicle	UnitsInvolved = 2 And County = 'MEADE'
			Motorcycle Only	UnitsInvolved = 1 And County = 'MEADE'
		Injury Status	No Casualty	NumberKilled = 0 And NumberInjured = 0 And County = 'MEADE'
			Fatality Greater than or equal to 1	NumberKilled <> 0 And County = 'MEADE'
			Injury greater than or equal to 1	NumberInjured <> 0 And County = 'MEADE'
		Master	All County Collisions	County = 'MEADE'
Jefferson County, KY	Highest cumulative amount of motorcycle involved collisions by county	Vehicle Status	Multiple Vehicles	UnitsInvolved <> 1 And UnitsInvolved <> 2 And County = 'JEFFERSON'
			Single Vehicle	UnitsInvolved = 2 And County = 'JEFFERSON'
			Motorcycle Only	UnitsInvolved = 1 And County = 'JEFFERSON'
		Injury Status	No Casualty	NumberKilled = 0 And NumberInjured = 0 And County = 'JEFFERSON'
			Fatality Greater than or equal to 1	NumberKilled <> 0 And County = 'JEFFERSON'
			Injury greater than or equal to 1	NumberInjured <> 0 And County = 'JEFFERSON'
		Master	All County Collisions	County = 'JEFFERSON'
Livingston County, KY	Higher percentage of motorcycle involved collisions resulting in	Vehicle Status	Multiple Vehicles	UnitsInvolved <> 1 And UnitsInvolved <> 2 And County = 'LIVINGSTON'
			Single Vehicle	UnitsInvolved = 2 And County = 'LIVINGSTON'
			Motorcycle Only	UnitsInvolved = 1 And County = 'LIVINGSTON'
		Injury Status	No Casualty	NumberKilled = 0 And NumberInjured = 0 And County = 'LIVINGSTON'
			Fatality Greater than or equal to 1	NumberKilled <> 0 And County = 'LIVINGSTON'
			Injury greater than or equal to 1	NumberInjured <> 0 And County = 'LIVINGSTON'
		Master	All County Collisions	County = 'LIVINGSTON'
Fayette County, KY	Second highest cumulative total of motorcycle involved collisions	Vehicle Status	Multiple Vehicles	UnitsInvolved <> 1 And UnitsInvolved <> 2 And County = 'FAYETTE'
			Single Vehicle	UnitsInvolved = 2 And County = 'FAYETTE'
			Motorcycle Only	UnitsInvolved = 1 And County = 'FAYETTE'
		Injury Status	No Casualty	NumberKilled = 0 And NumberInjured = 0 And County = 'FAYETTE'
			Fatality Greater than or equal to 1	NumberKilled <> 0 And County = 'FAYETTE'
			Injury greater than or equal to 1	NumberInjured <> 0 And County = 'FAYETTE'
		Master	All County Collisions	County = 'FAYETTE'

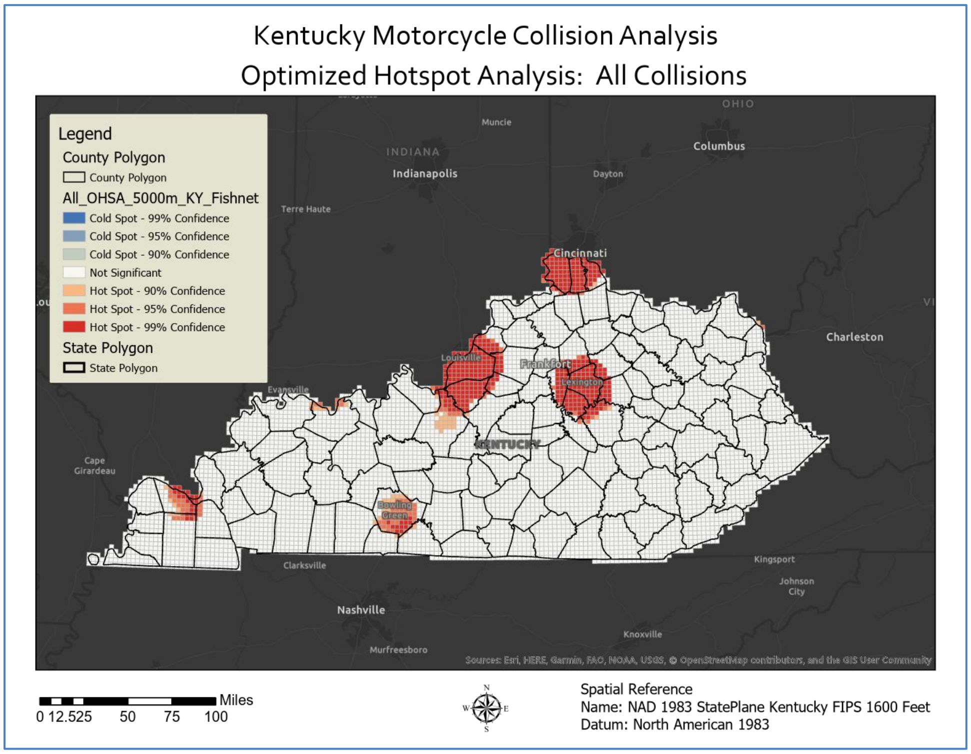
Appendix B: Results

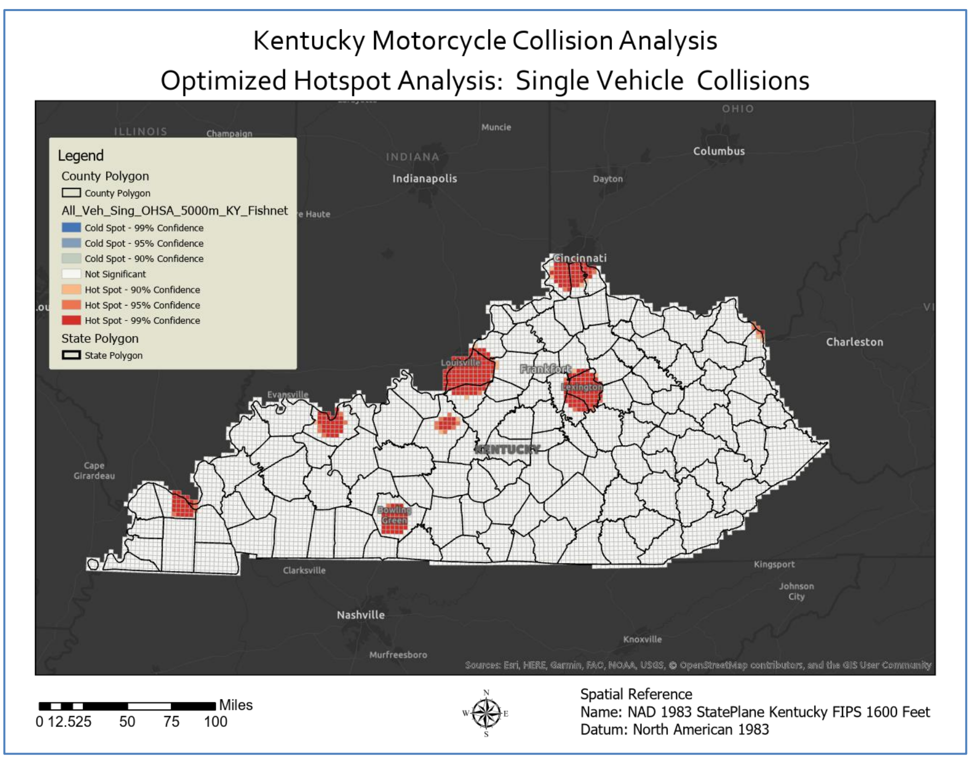
Study Area	Motivation	Category	# of Records	Status	100m	250m	500m	5000m	**Z m	Results
Kentucky	Statewide comparrison - acts as a control for the specific, county based analysis	Vehicle Status	8948	Complete	NC	NC	NC	CI	NC	
			9352	Complete	NC	NC	NC	CI	NC	
			8322	Complete	NC	NC	NC	CI	NC	
		Injury Status	6260	Complete	NC	NC	NC	CI	NC	
			842	Complete	NC	NC	NC	CI	NC	
			11408	Complete	NC	NC	NC	CI	NC	
		Master	18300	Complete	NC	NC	NC	CI	NC	
Meade County, KY	Higher percentage of motorcycle involved collisions resulting in fatalities by county	Vehicle Status	3	Failed	NC	NC	NC	NC	NC	*ERROR 001570
			44	Complete	NC	CV	CI	NC	NC	
			61	Complete	NC	NC	CV	NC	NC	
		Injury Status	25	Failed	NC	NC	NC	NC	NC	*ERROR 001570
			16	Failed	NC	NC	NC	NC	NC	*ERROR 001570
			71	Complete	NC	NC	CV	NC	NC	
		Master	108	Complete	CI	CI	CV	NC	NC	
Jefferson County, KY	Highest cumulative amount of motorcycle involved collisions by county	Vehicle Status	157	Complete	CI	CV	CV	NC	CI	
			2099	Complete	CI	CV	CI	NC	CI	
			904	Complete	CV	CV	CI	NC	CI	
		Injury Status	1109	Complete	NC	CV	NC	NC	CI	
			141	Complete	NC	CV	CV	NC	CI	
			1951	Complete	CV	CV	NC	NC	CI	
		Master	3160	Complete	CV	CV	CI	NC	CI	
Livingston County, KY	Higher percentage of motorcycle involved collisions resulting in injuries by county total	Vehicle Status	1	Failed	NC	NC	NC	NC	NC	*ERROR 001570
			17	Failed	NC	NC	NC	NC	NC	*ERROR 001570
			39	Complete	NC	NC	CV	NC	CI	
		Injury Status	10	Failed	NC	NC	NC	NC	NC	*ERROR 001570
			1	Failed	NC	NC	NC	NC	NC	*ERROR 001570
			46	Complete	NC	NC	CV	NC	CI	
		Master	57	Complete	NC	NC	CV	NC	CI	
Fayette County, KY	Second highest cumulative total of motorcycle involved collisions resulting in fatality *and* injury	Vehicle Status	50	Complete	NC	CI	CV	NC	CI	
			837	Complete	NC	CV	NC	NC	CI	
			384	Complete	NC	CV	NC	NC	CI	
		Injury Status	506	Complete	NC	CV	CI	NC	CI	
			36	Complete	NC	CI	CI	NC	CI	
			735	Complete	NC	CV	NC	NC	CI	
		Master	1271	Complete	CV	CI	CI	NC	CI	
	*ERROR 001570	The analysis option you selected requires a minimum of 30 points to be inside the bounding polygon area(s)								
	**Z m	Tool was completed using automatically generated cell size								
		CV	Completed, Viable Result							
		NC	Not Completed							
		CI	Completed, Inconclusive							

Appendix C: Final Results

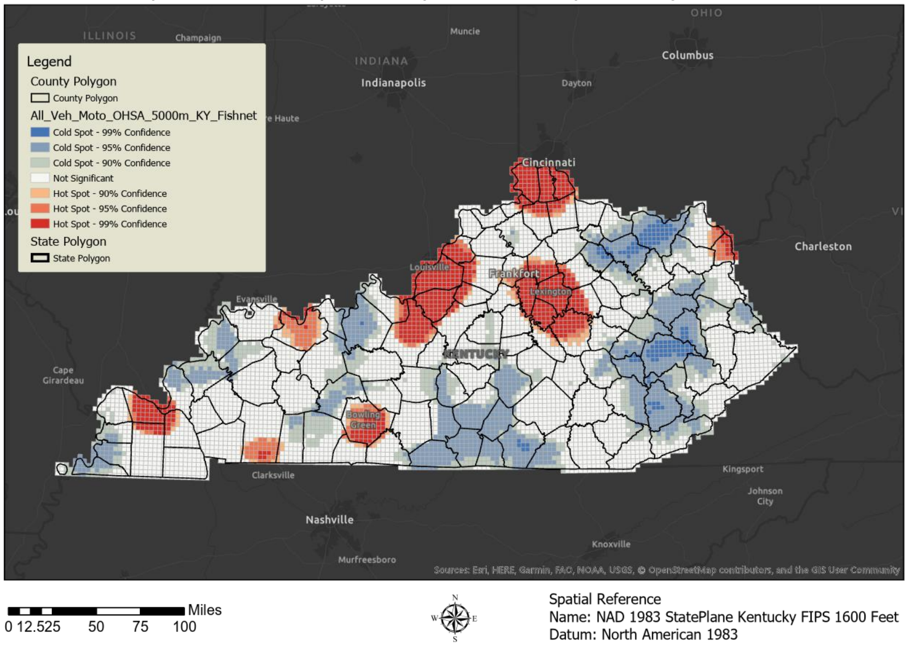
Study Area	Motivation	Focus Area	# of Records	Status	Final Results
Meade County, KY	Higher percentage of motorcycle involved collisions resulting in fatalities by county	All County Collisions	108	Incomplete	No viable locations identified - county does not contain state-maintained roads meeting or exceeding 60,000 AADT.
Jefferson County, KY	Highest cumulative amount of motorcycle involved collisions by county	All County Collisions	3160	Complete	Multiple locations with need and infrastructure capable of supporting a motorcycle lane identified.
Livingston County, KY	Higher percentage of motorcycle involved collisions resulting in injuries by county total	All County Collisions	57	Incomplete	No viable locations identified - county does not contain state-maintained roads meeting or exceeding 60,000 AADT intersecting the identified hot spots.
Fayette County, KY	Second highest cumulative total of motorcycle involved collisions resulting in fatality *and* injury	All County Collisions	1271	Complete	Multiple locations with need and infrastructure capable of supporting a motorcycle lane identified.

Appendix D: Commonwealth of Kentucky

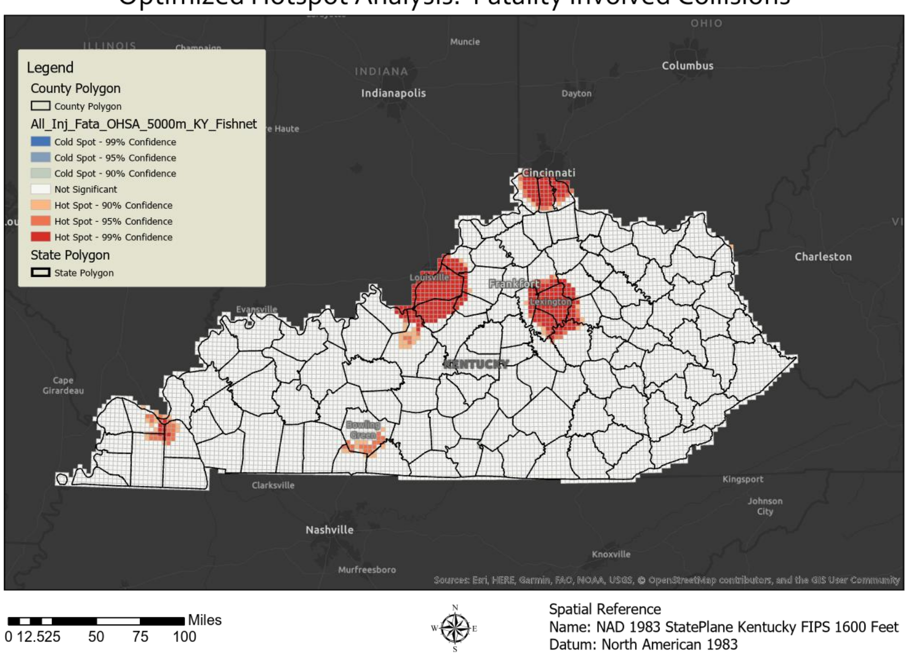




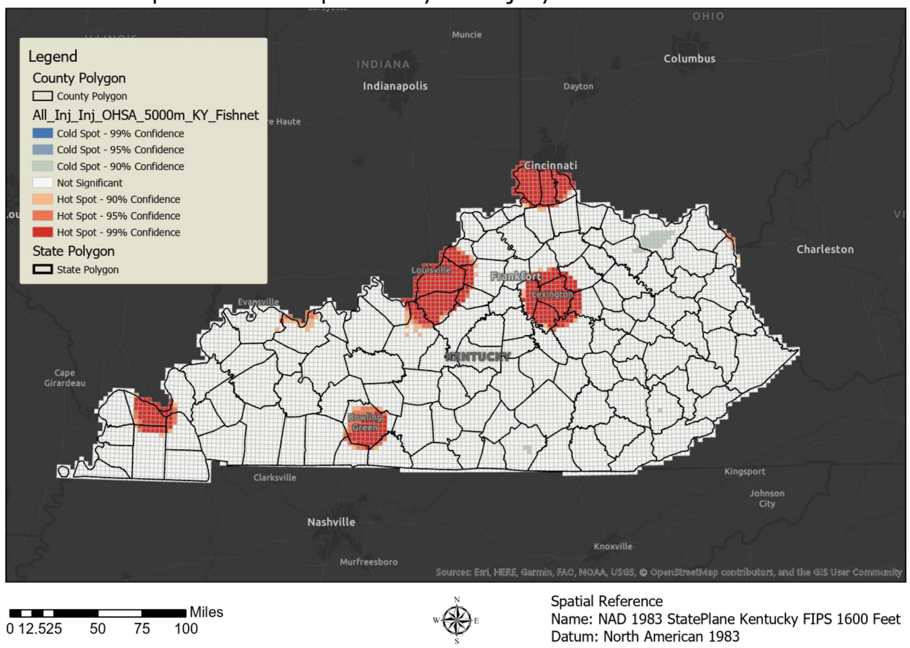
Kentucky Motorcycle Collision Analysis
Optimized Hotspot Analysis: Motorcycle Only Collisions



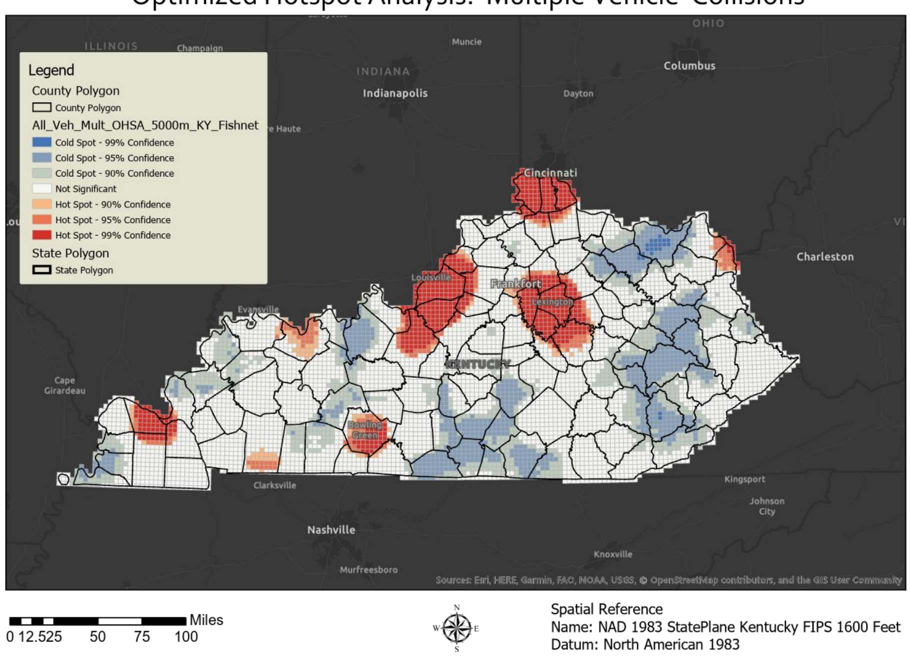
Kentucky Motorcycle Collision Analysis
Optimized Hotspot Analysis: Fatality Involved Collisions

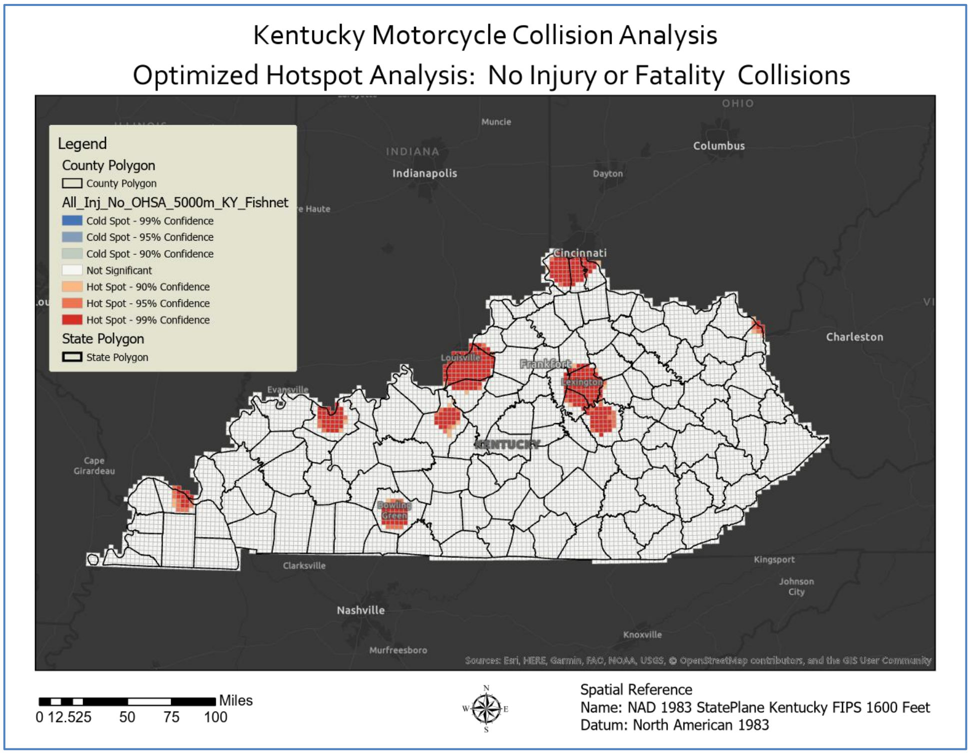


Kentucky Motorcycle Collision Analysis
Optimized Hotspot Analysis: Injury Involved Collisions

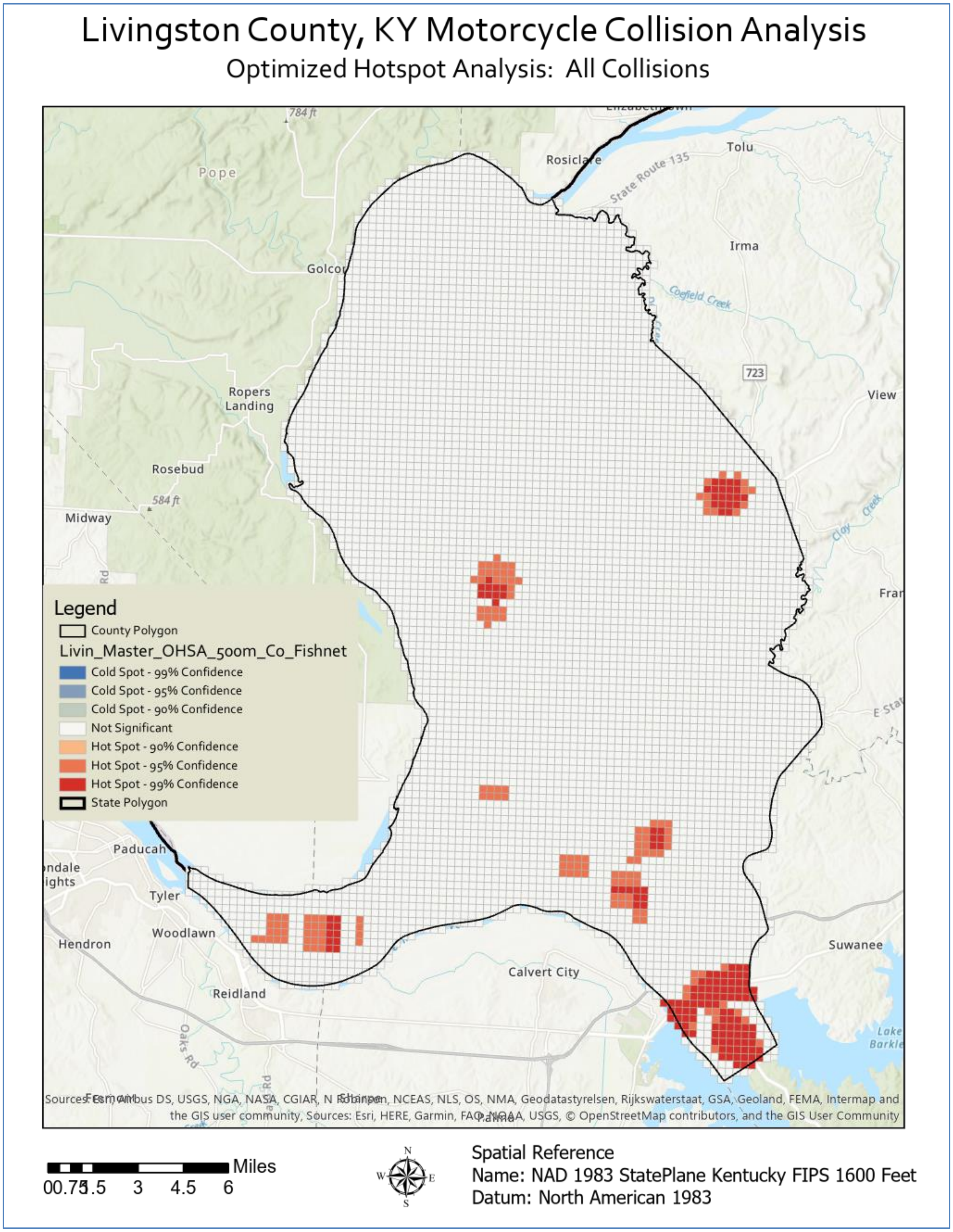


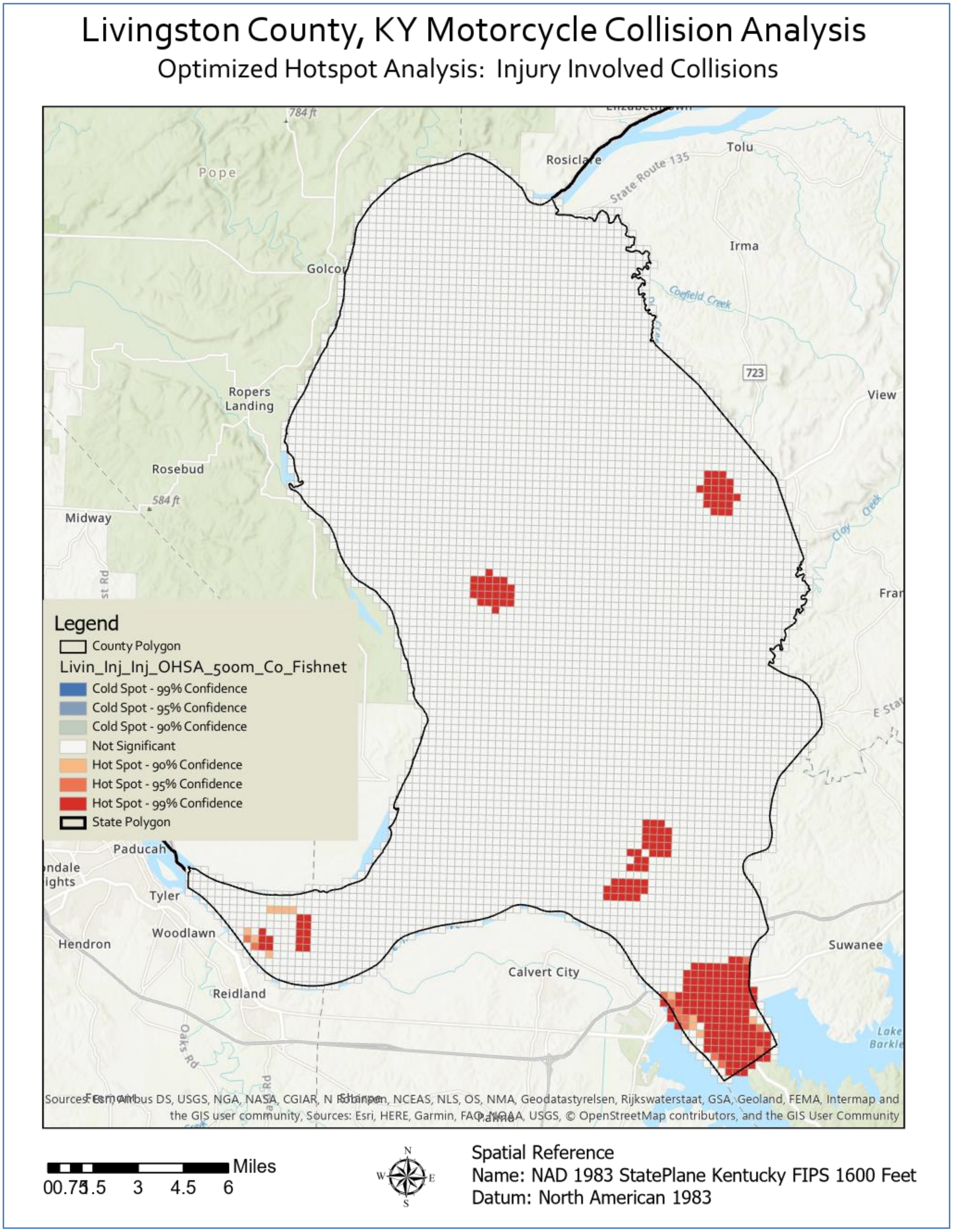
Kentucky Motorcycle Collision Analysis
Optimized Hotspot Analysis: Multiple Vehicle Collisions




Kentucky Motorcycle Collision Analysis
Optimized Hotspot Analysis: No Injury or Fatality Collisions
Legend
County Polygon
County Polygon
All_Inj_No_OHSA_5000m_KY_Fishnet
Cold Spot - 99% Confidence
Cold Spot - 95% Confidence
Cold Spot - 90% Confidence
Not Significant
Hot Spot - 90% Confidence
Hot Spot - 95% Confidence
Hot Spot - 99% Confidence
State Polygon
State Polygon
INDIANA
Indianapolis
Muncie
Dayton
OHIO
Columbus
Cincinnati
Charleston
Louisville
Frankfort
Lexington
Evansville
KENTUCKY
Cape Girardeau
Bowling Green
Clarksville
Nashville
Murfreesboro
Knoxville
Kingsport
Johnson City
Sources: Esri, HERE, Garmin, FAO, NOAA, USGS, © OpenStreetMap contributors, and the GIS User Community
Miles
0 12.525 50 75 100
N
W
E
S
Spatial Reference
Name: NAD 1983 StatePlane Kentucky FIPS 1600 Feet
Datum: North American 1983

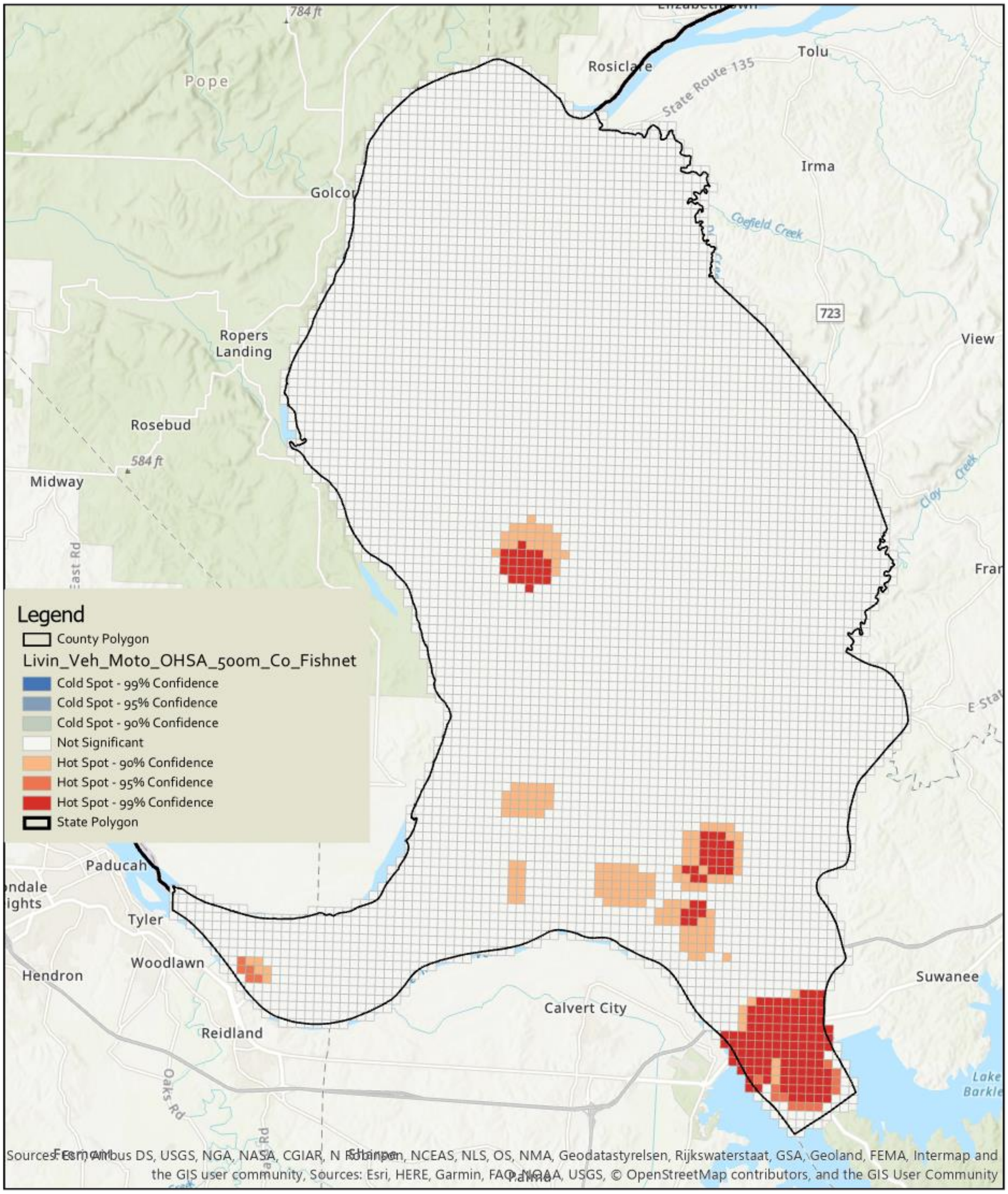
Appendix E: Livingston County




Livingston County, KY Motorcycle Collision Analysis
Optimized Hotspot Analysis: Injury Involved Collisions
Legend
County Polygon
Livin_Inj_Inj_OHSA_500m_Co_Fishnet
Cold Spot - 99% Confidence
Cold Spot - 95% Confidence
Cold Spot - 90% Confidence
Not Significant
Hot Spot - 90% Confidence
Hot Spot - 95% Confidence
Hot Spot - 99% Confidence
State Polygon
Pope
Rosiclare
Tolu
Irma
Golconda
Ropers Landing
Rosebud
Midway
View
Paducah
Tyler
Woodlawn
Hendron
Reidland
Calvert City
Suwanee
Miles
0 0.75 1.5 3 4.5 6
Spatial Reference
Name: NAD 1983 StatePlane Kentucky FIPS 1600 Feet
Datum: North American 1983

Livingston County, KY Motorcycle Collision Analysis

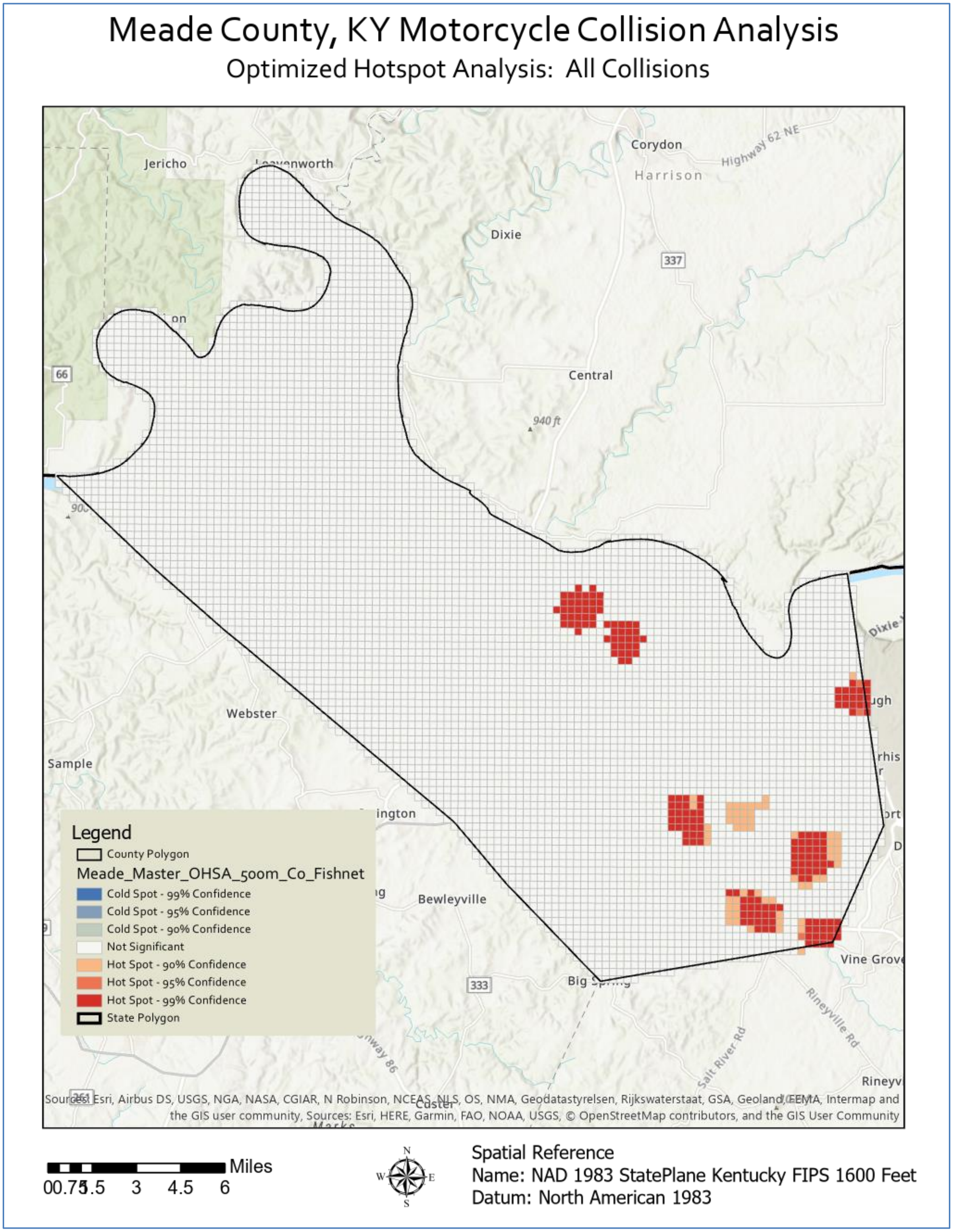
Optimized Hotspot Analysis: Motorcycle Only Collisions



Miles
0 0.75 1.5 3 4.5 6

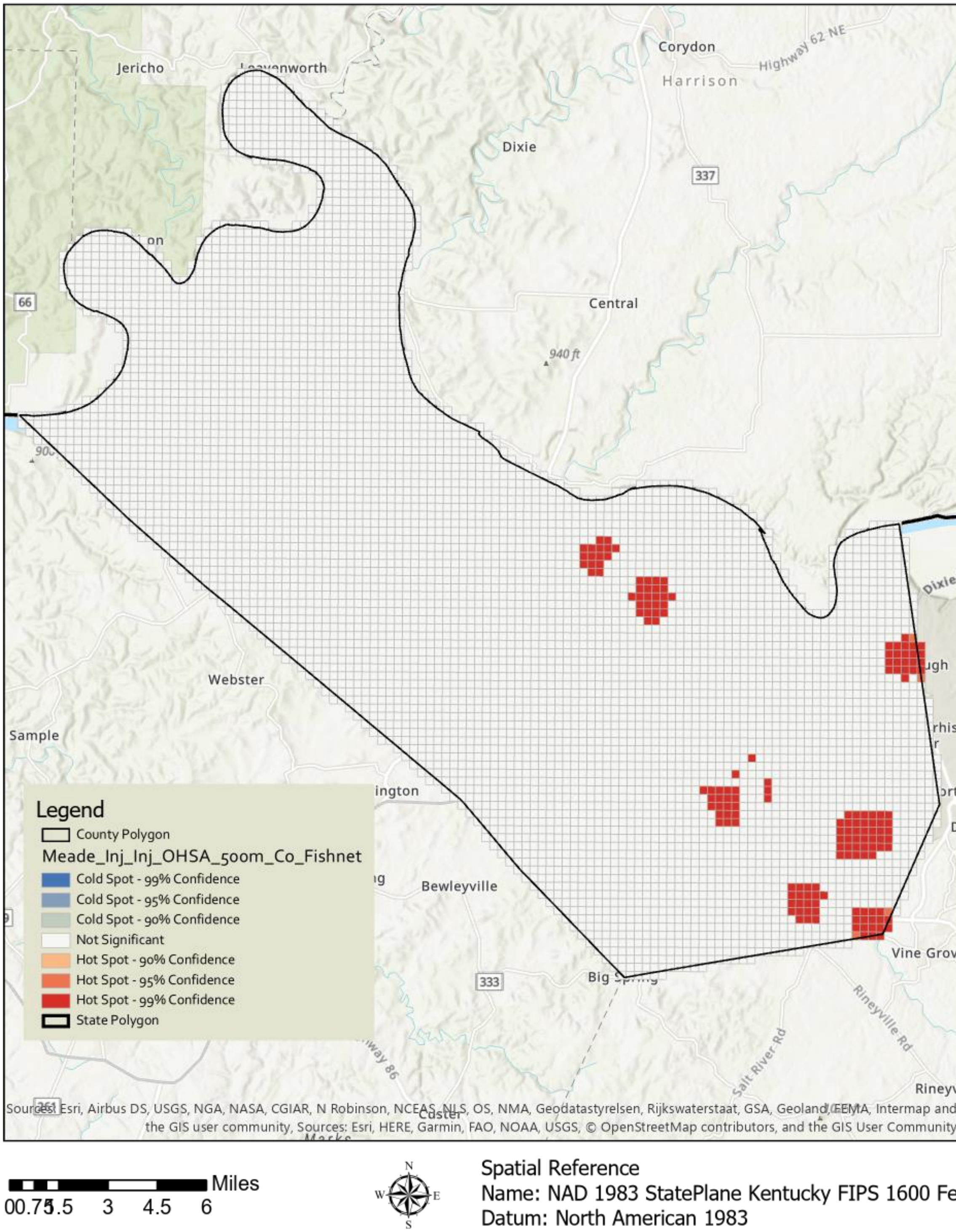
Spatial Reference
Name: NAD 1983 StatePlane Kentucky FIPS 1600 Feet
Datum: North American 1983

Appendix F: Meade County



Meade County, KY Motorcycle Collision Analysis

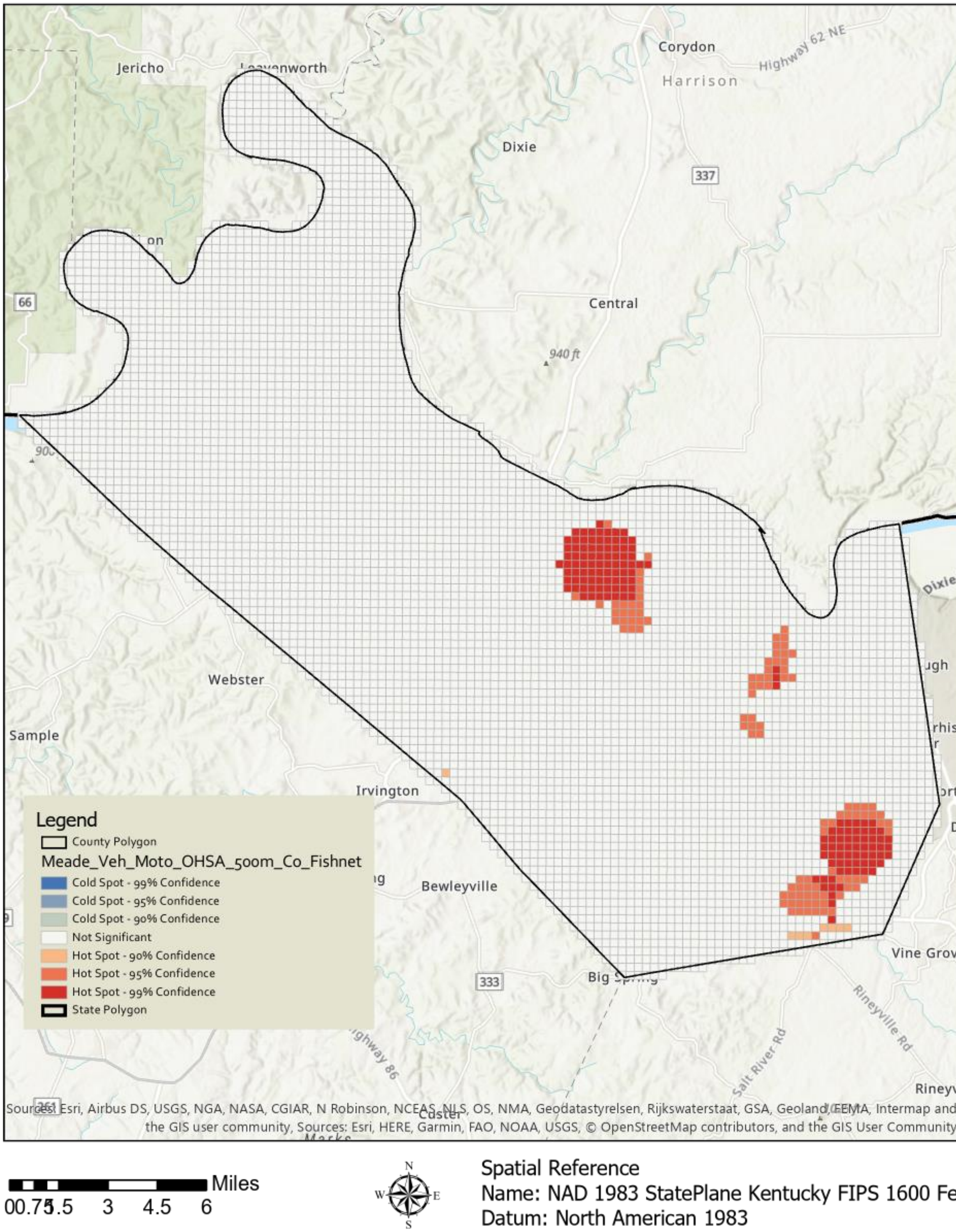
Optimized Hotspot Analysis: Injury Involved Collisions



Spatial Reference
Name: NAD 1983 StatePlane Kentucky FIPS 1600 Feet
Datum: North American 1983

Meade County, KY Motorcycle Collision Analysis

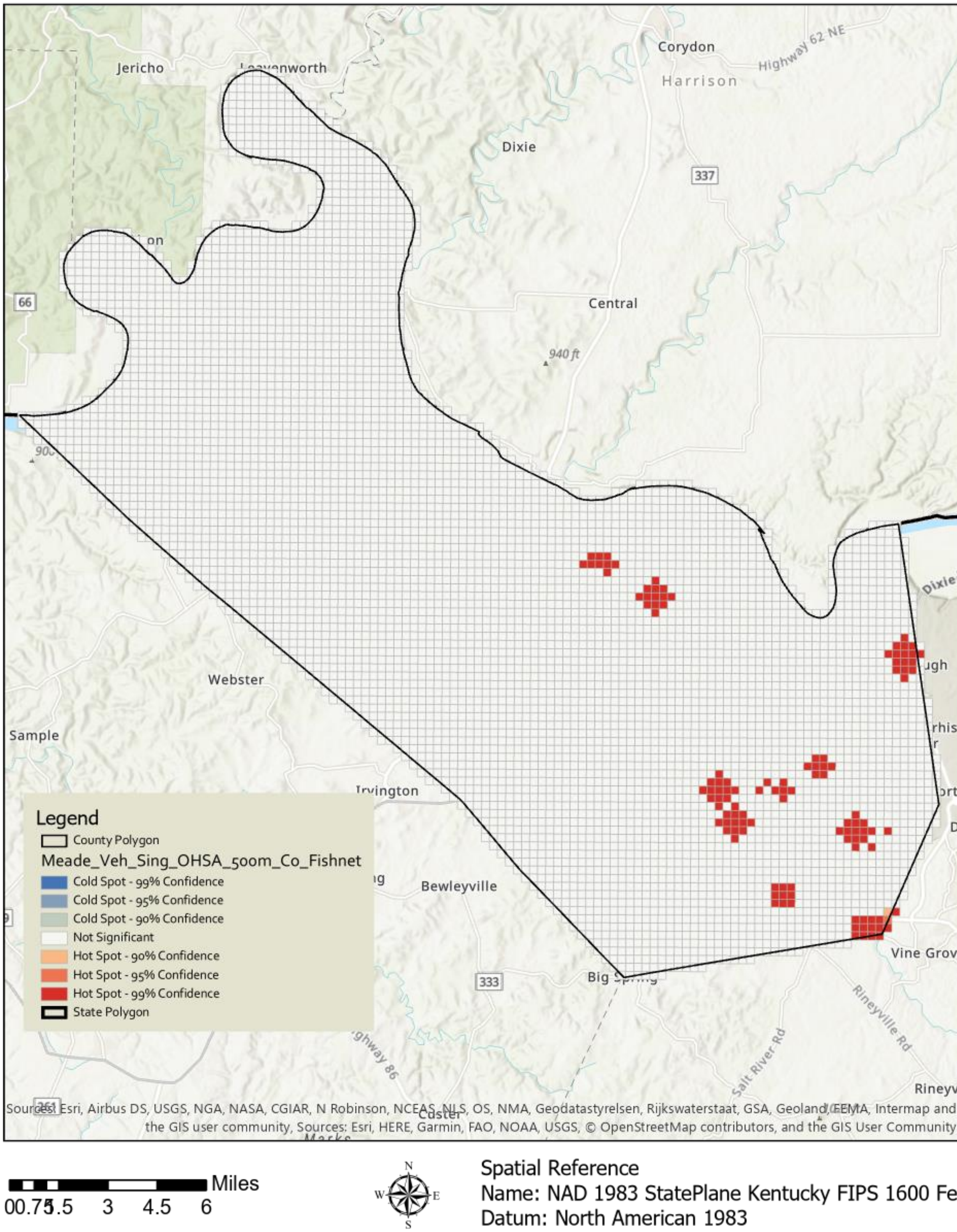
Optimized Hotspot Analysis: Motorcycle Only Collisions



Spatial Reference
Name: NAD 1983 StatePlane Kentucky FIPS 1600 Feet
Datum: North American 1983

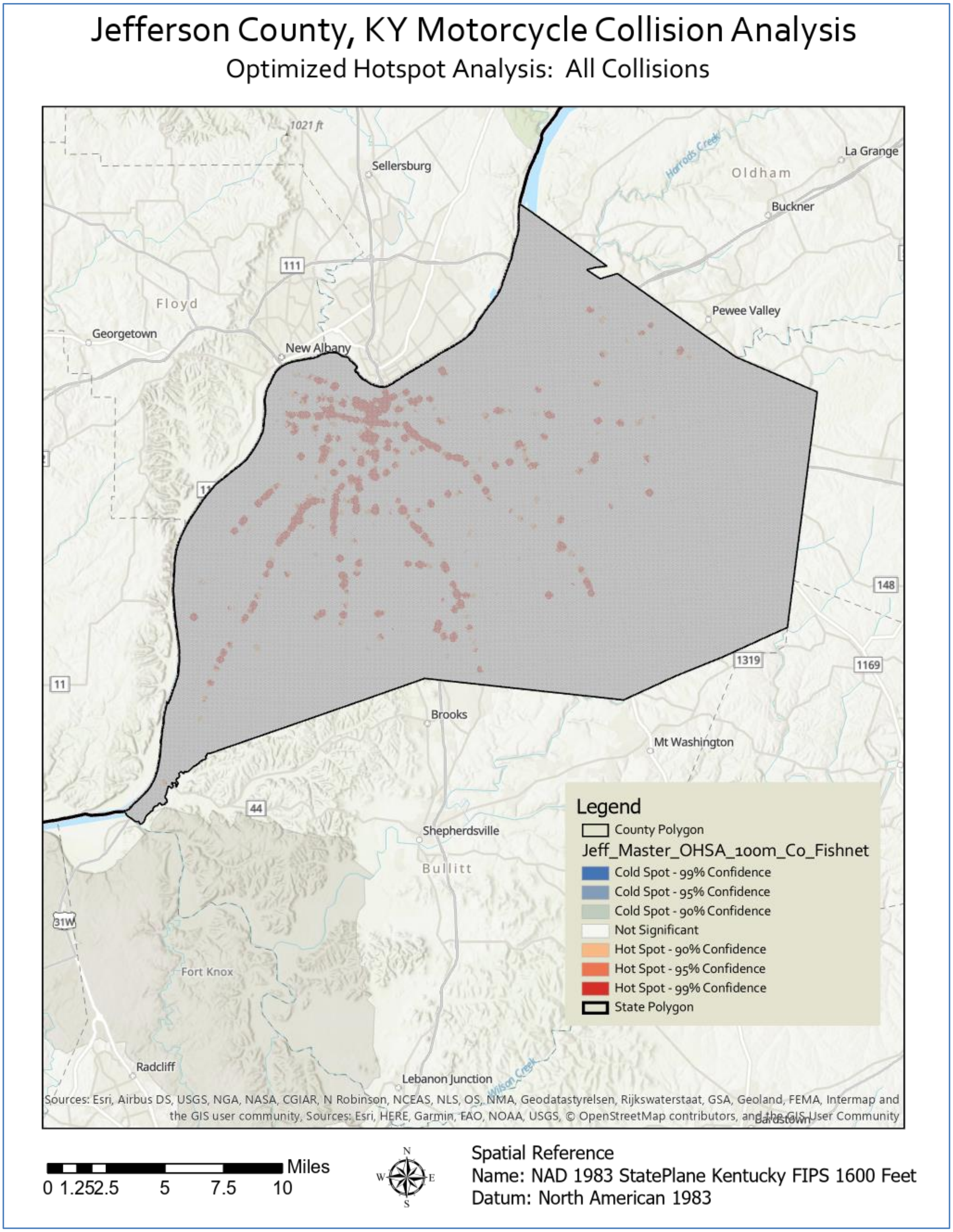
Meade County, KY Motorcycle Collision Analysis

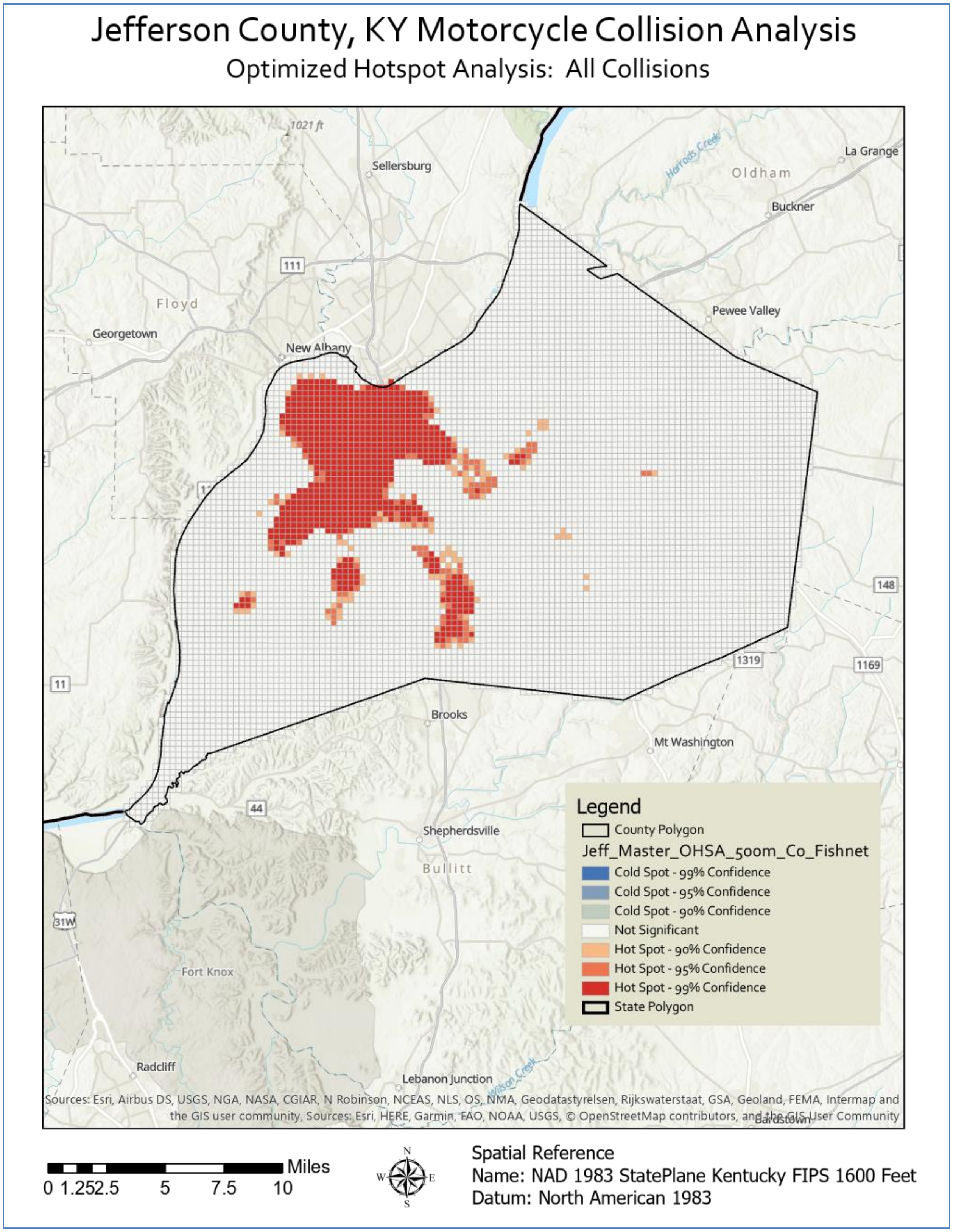
Optimized Hotspot Analysis: Single Vehicle Collisions



Spatial Reference
Name: NAD 1983 StatePlane Kentucky FIPS 1600 Feet
Datum: North American 1983

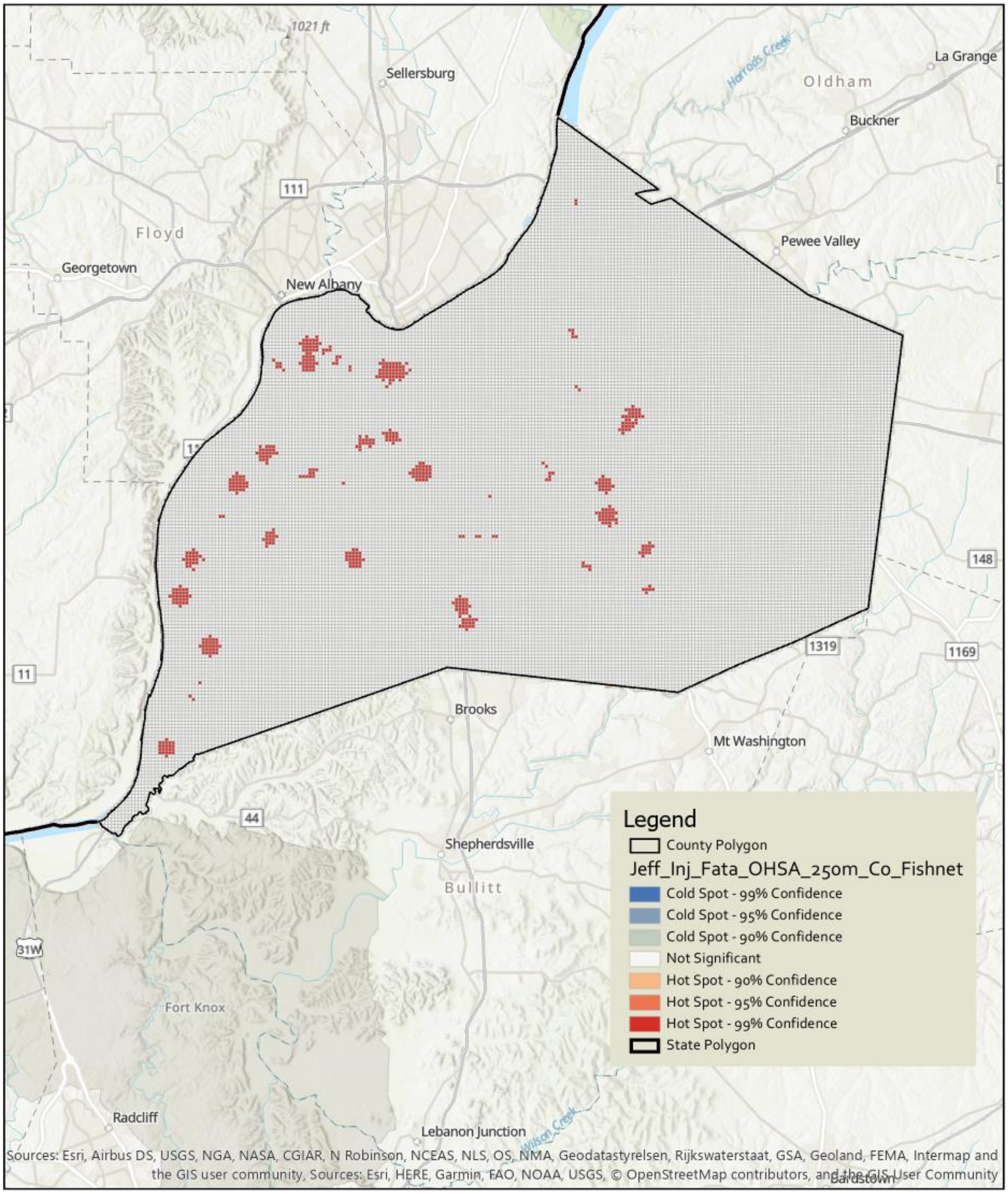
Appendix G: Jefferson County




Jefferson County, KY Motorcycle Collision Analysis
Optimized Hotspot Analysis: All Collisions
1021 ft
Sellersburg
Harrods Creek
La Grange
Oldham
Buckner
111
Floyd
Georgetown
New Albany
Pewee Valley
148
11
1319
1169
Brooks
Mt Washington
44
Shepherdsville
Bullitt
31W
Fort Knox
Radcliff
Lebanon Junction
Wilson Creek
Legend
County Polygon
Jeff_Master_OHSA_500m_Co_Fishnet
Cold Spot - 99% Confidence
Cold Spot - 95% Confidence
Cold Spot - 90% Confidence
Not Significant
Hot Spot - 90% Confidence
Hot Spot - 95% Confidence
Hot Spot - 99% Confidence
State Polygon
Sources: Esri, Airbus DS, USGS, NGA, NASA, CGIAR, N Robinson, NCEAS, NLS, OS, NMA, Geodatastyrelsen, Rijkswaterstaat, GSA, Geoland, FEMA, Intermap and the GIS user community, Sources: Esri, HERE, Garmin, FAO, NOAA, USGS, © OpenStreetMap contributors, and the GIS User Community
Bardstown
Miles
0 1.252.5 5 7.5 10
N
W
E
S
Spatial Reference
Name: NAD 1983 StatePlane Kentucky FIPS 1600 Feet
Datum: North American 1983

Jefferson County, KY Motorcycle Collision Analysis

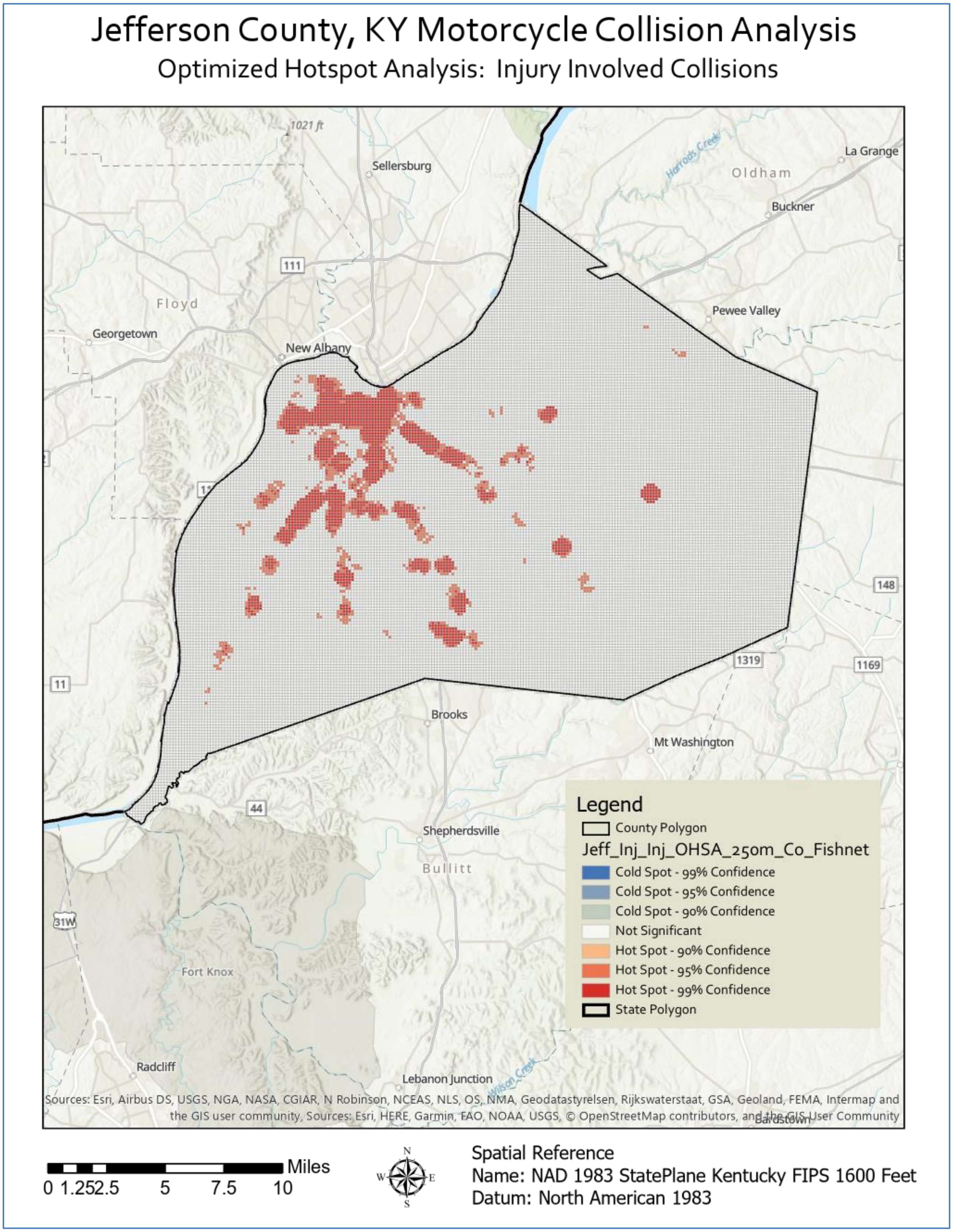
Optimized Hotspot Analysis: Fatality Involved Collisions

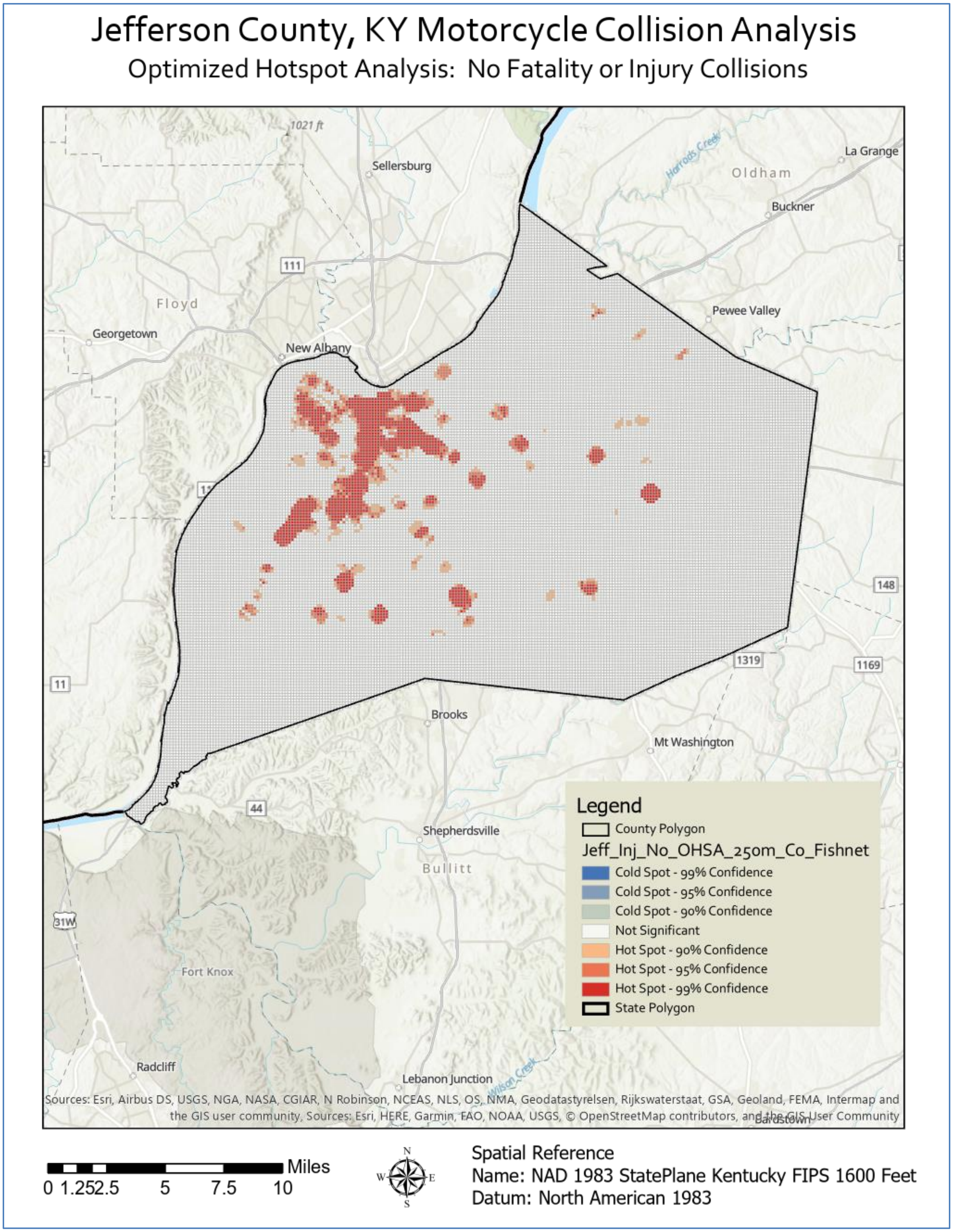


Miles
0 1.252.5 5 7.5 10

N W E S

Spatial Reference
Name: NAD 1983 StatePlane Kentucky FIPS 1600 Feet
Datum: North American 1983

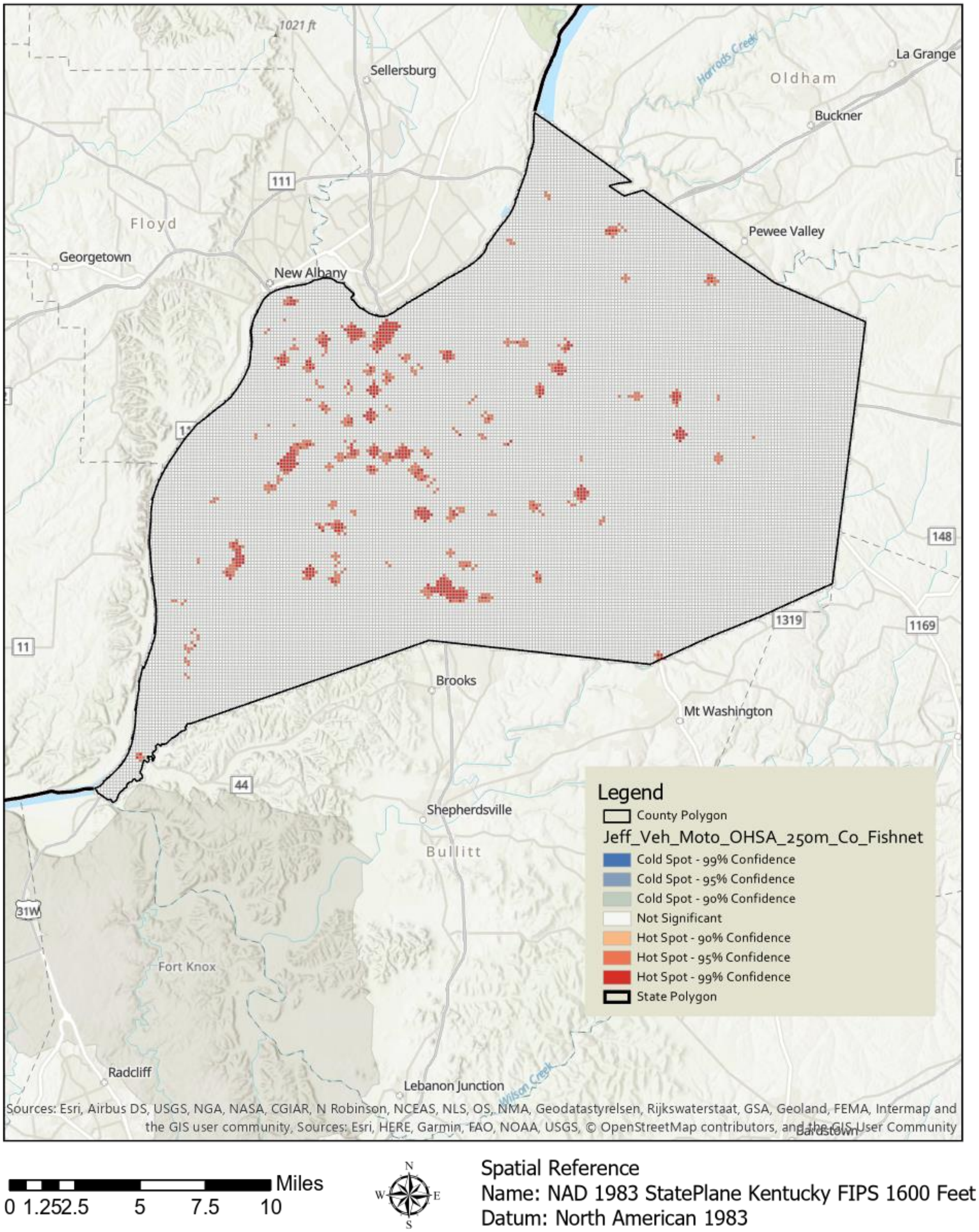

Jefferson County, KY Motorcycle Collision Analysis
Optimized Hotspot Analysis: Injury Involved Collisions
Sellersburg
La Grange
Oldham
Buckner
Floyd
Georgetown
New Albany
Pewee Valley
Brooks
Mt Washington
Shepherdsville
Bullitt
Fort Knox
Radcliff
Lebanon Junction
Legend
County Polygon
Jeff_Inj_Inj_OHSA_250m_Co_Fishnet
Cold Spot - 99% Confidence
Cold Spot - 95% Confidence
Cold Spot - 90% Confidence
Not Significant
Hot Spot - 90% Confidence
Hot Spot - 95% Confidence
Hot Spot - 99% Confidence
State Polygon
Sources: Esri, Airbus DS, USGS, NGA, NASA, CGIAR, N Robinson, NCEAS, NLS, OS, NMA, Geodatastyrelsen, Rijkswaterstaat, GSA, Geoland, FEMA, Intermap and the GIS user community, Sources: Esri, HERE, Garmin, FAO, NOAA, USGS, © OpenStreetMap contributors, and the GIS User Community
Miles
0 1.25 2.5 5 7.5 10
Spatial Reference
Name: NAD 1983 StatePlane Kentucky FIPS 1600 Feet
Datum: North American 1983



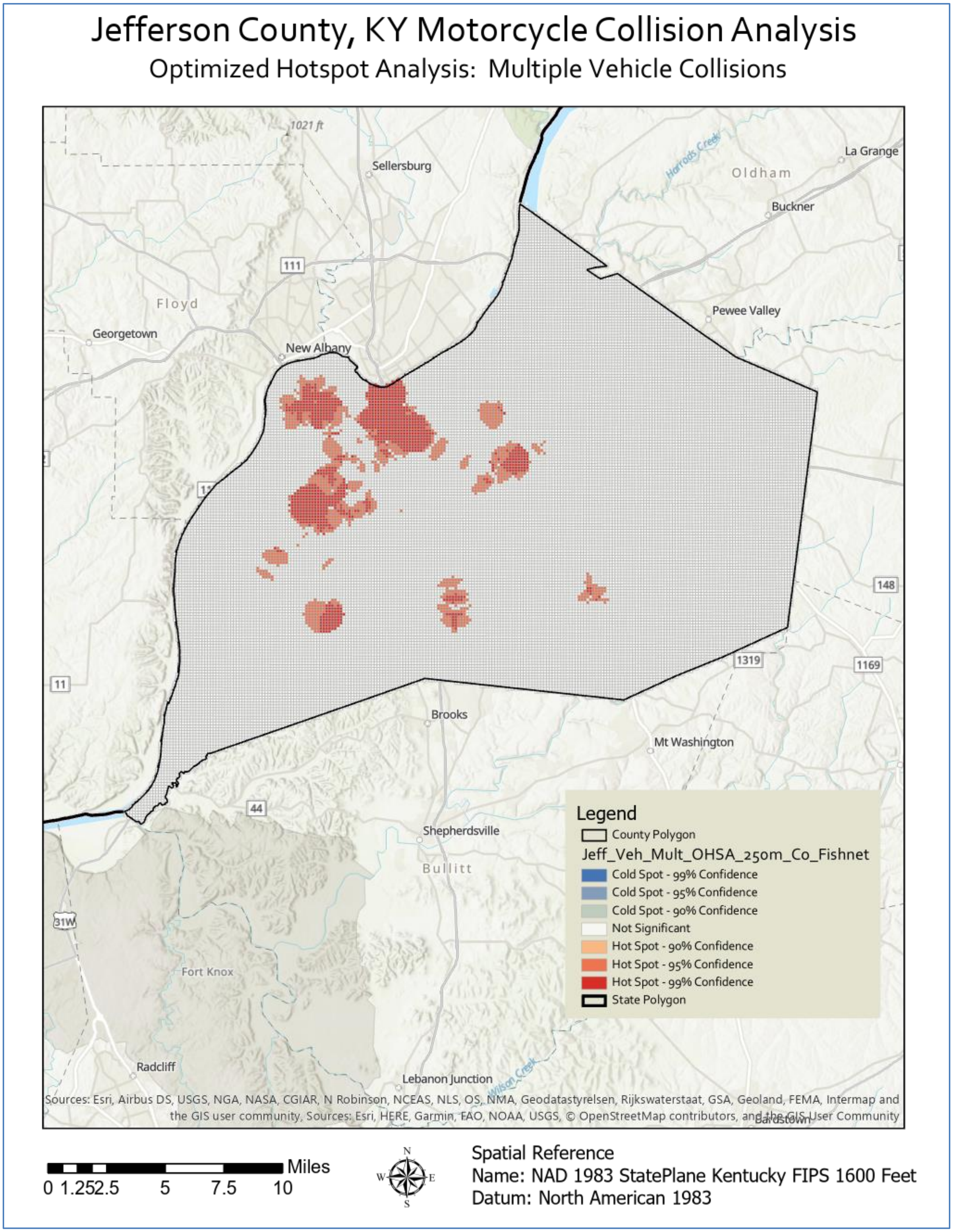
Jefferson County, KY Motorcycle Collision Analysis
Optimized Hotspot Analysis: No Fatality or Injury Collisions
Sellersburg
Oldham
La Grange
Buckner
Floyd
Georgetown
New Albany
Pewee Valley
Brooks
Mt Washington
Shepherdsville
Bullitt
Fort Knox
Radcliff
Lebanon Junction
Legend
County Polygon
Jeff_Inj_No_OHSA_250m_Co_Fishnet
Cold Spot - 99% Confidence
Cold Spot - 95% Confidence
Cold Spot - 90% Confidence
Not Significant
Hot Spot - 90% Confidence
Hot Spot - 95% Confidence
Hot Spot - 99% Confidence
State Polygon
Sources: Esri, Airbus DS, USGS, NGA, NASA, CGIAR, N Robinson, NCEAS, NLS, OS, NMA, Geodatastyrelsen, Rijkswaterstaat, GSA, Geoland, FEMA, Intermap and the GIS user community, Sources: Esri, HERE, Garmin, FAO, NOAA, USGS, © OpenStreetMap contributors, and the GIS User Community
0 1.25 2.5 5 7.5 10 Miles
Spatial Reference
Name: NAD 1983 StatePlane Kentucky FIPS 1600 Feet
Datum: North American 1983

Jefferson County, KY Motorcycle Collision Analysis

Optimized Hotspot Analysis: Motorcycle Only Collisions

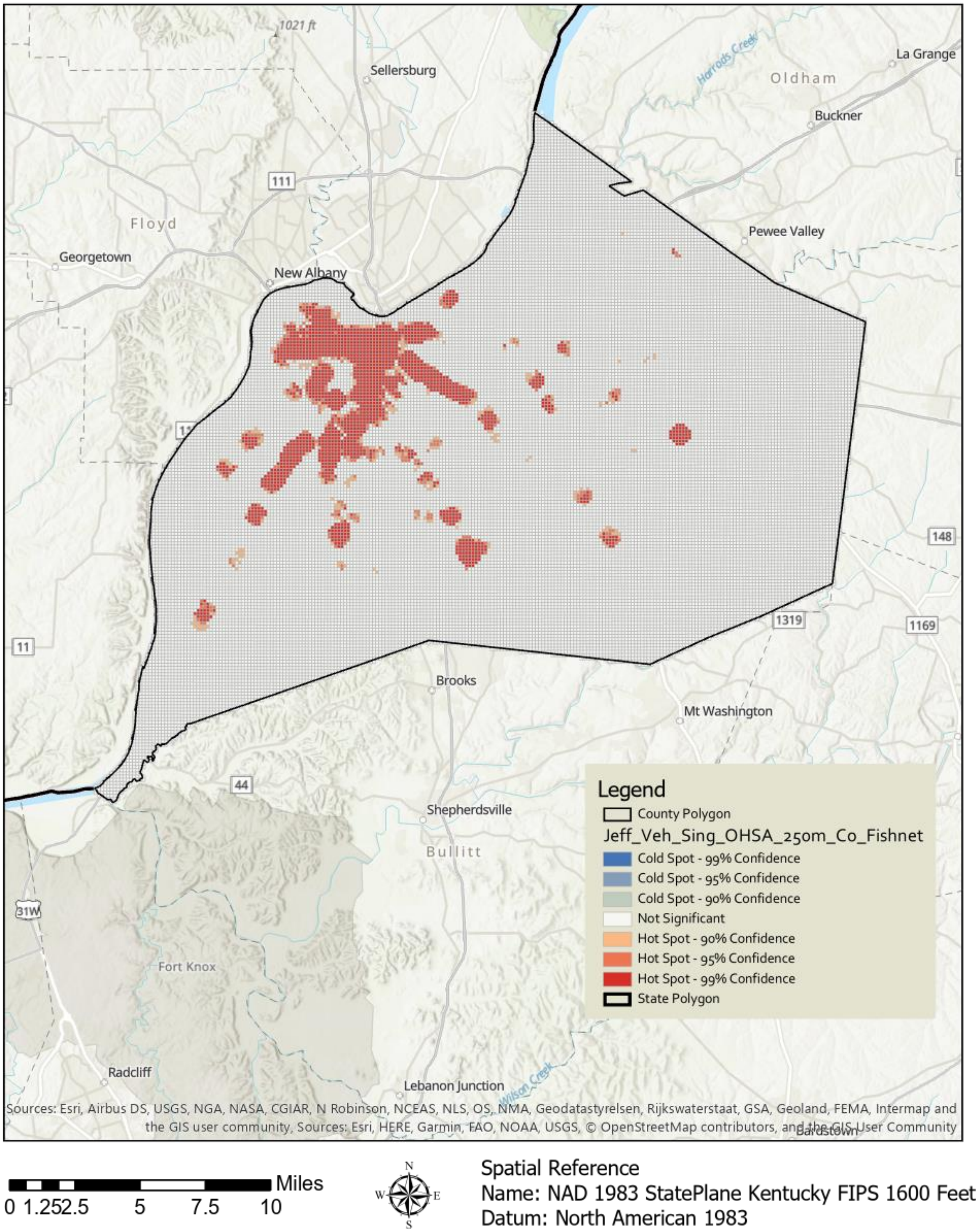


Spatial Reference
Name: NAD 1983 StatePlane Kentucky FIPS 1600 Feet
Datum: North American 1983

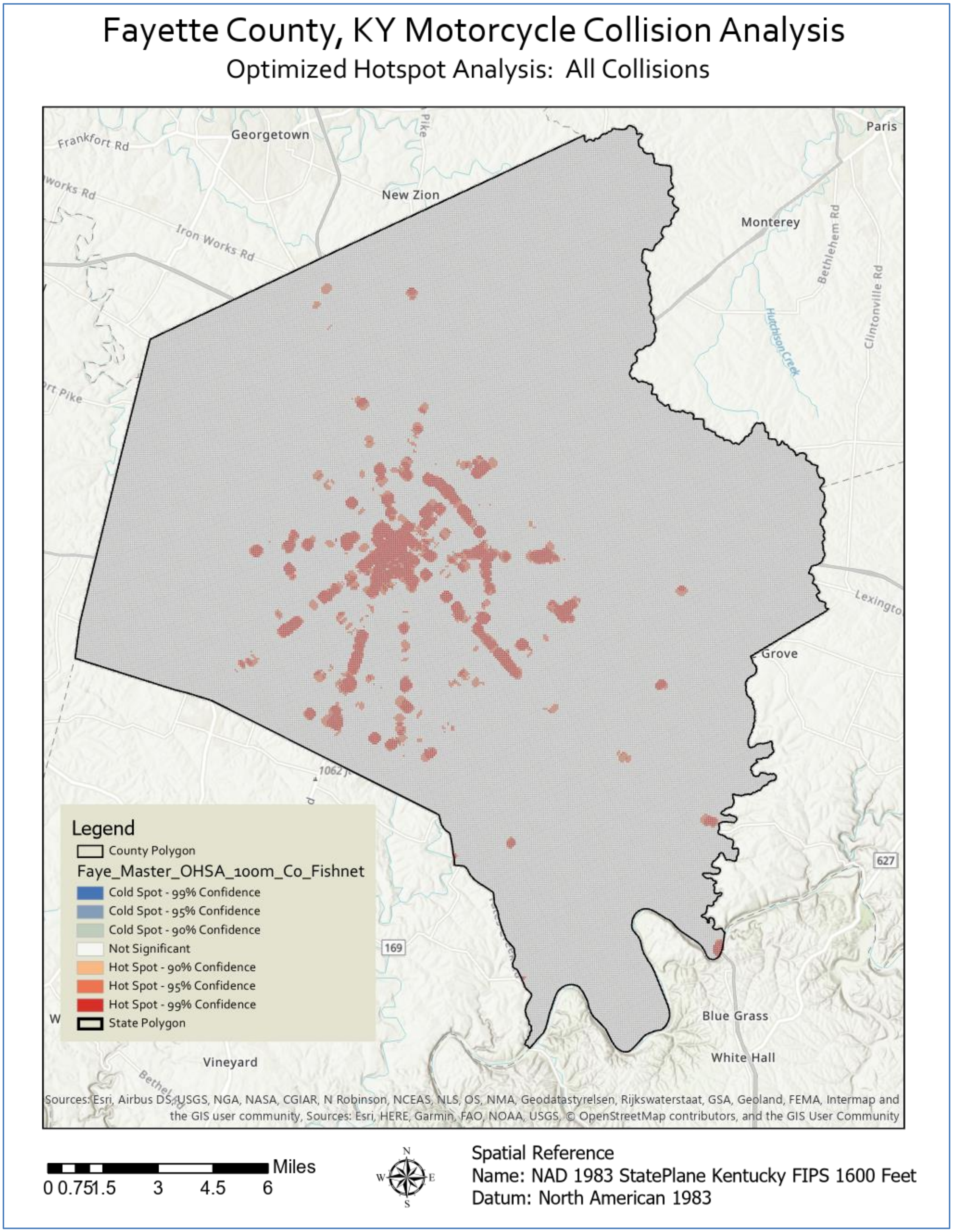

Jefferson County, KY Motorcycle Collision Analysis
Optimized Hotspot Analysis: Multiple Vehicle Collisions
Sellersburg
Oldham
La Grange
Buckner
Floyd
Georgetown
New Albany
Pewee Valley
Brooks
Mt Washington
Shepherdsville
Bullitt
Fort Knox
Radcliff
Lebanon Junction
Legend
County Polygon
Jeff_Veh_Mult_OHSA_250m_Co_Fishnet
Cold Spot - 99% Confidence
Cold Spot - 95% Confidence
Cold Spot - 90% Confidence
Not Significant
Hot Spot - 90% Confidence
Hot Spot - 95% Confidence
Hot Spot - 99% Confidence
State Polygon
Sources: Esri, Airbus DS, USGS, NGA, NASA, CGIAR, N Robinson, NCEAS, NLS, OS, NMA, Geodatastyrelsen, Rijkswaterstaat, GSA, Geoland, FEMA, Intermap and the GIS user community, Sources: Esri, HERE, Garmin, FAO, NOAA, USGS, © OpenStreetMap contributors, and the GIS User Community
0 1.25 2.5 5 7.5 10 Miles
Spatial Reference
Name: NAD 1983 StatePlane Kentucky FIPS 1600 Feet
Datum: North American 1983

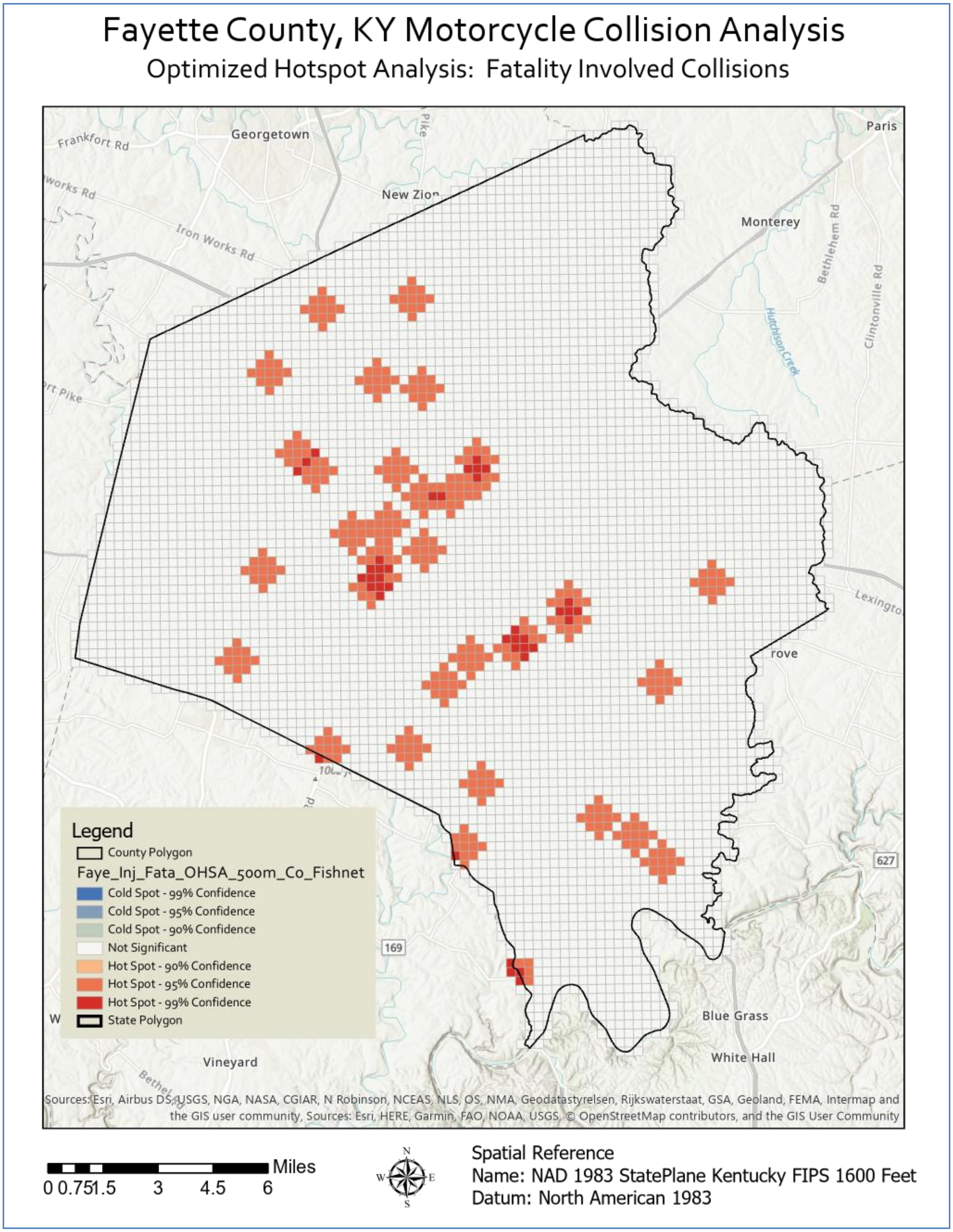
Jefferson County, KY Motorcycle Collision Analysis

Optimized Hotspot Analysis: Single Vehicle Collisions

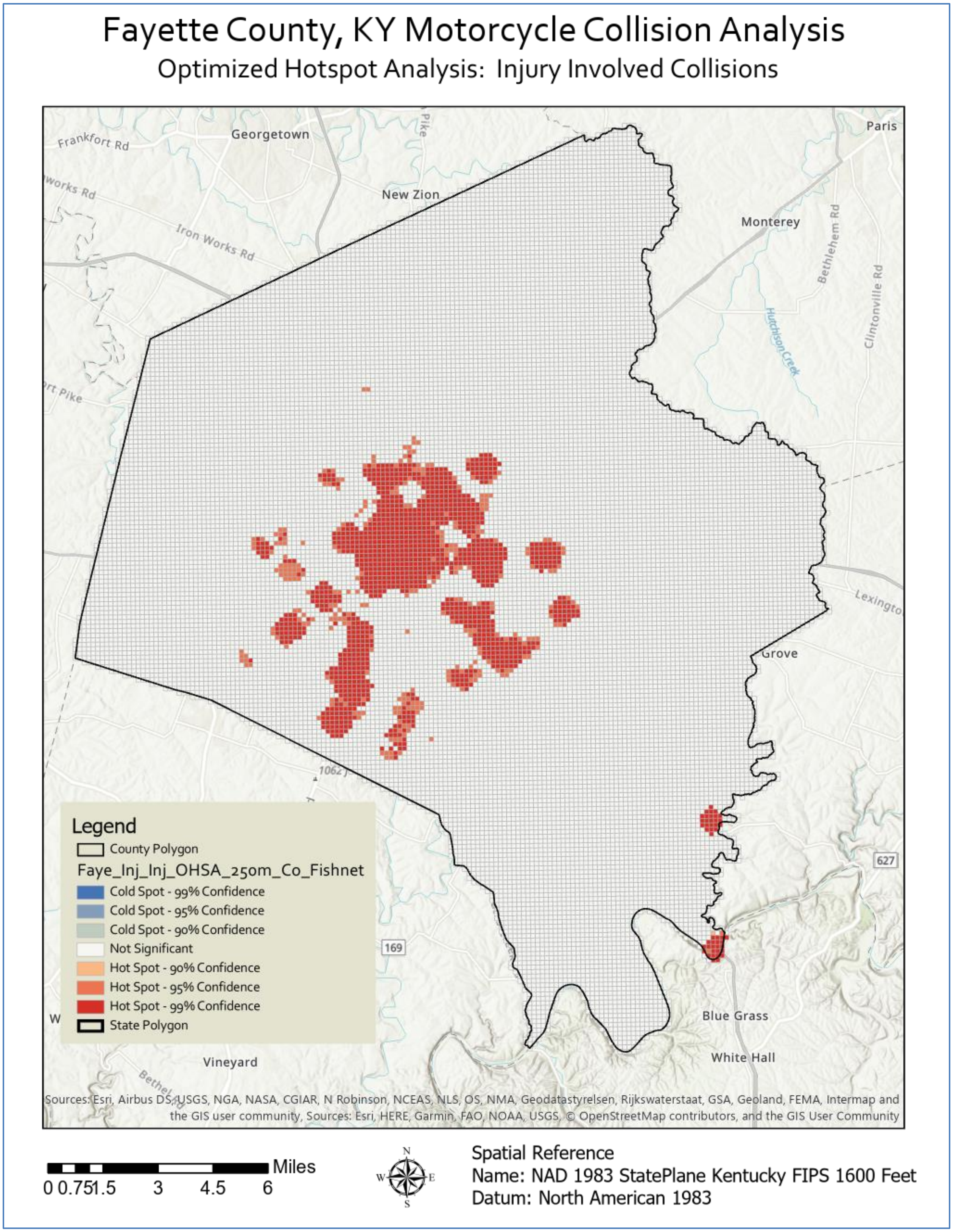


Appendix H: Fayette County



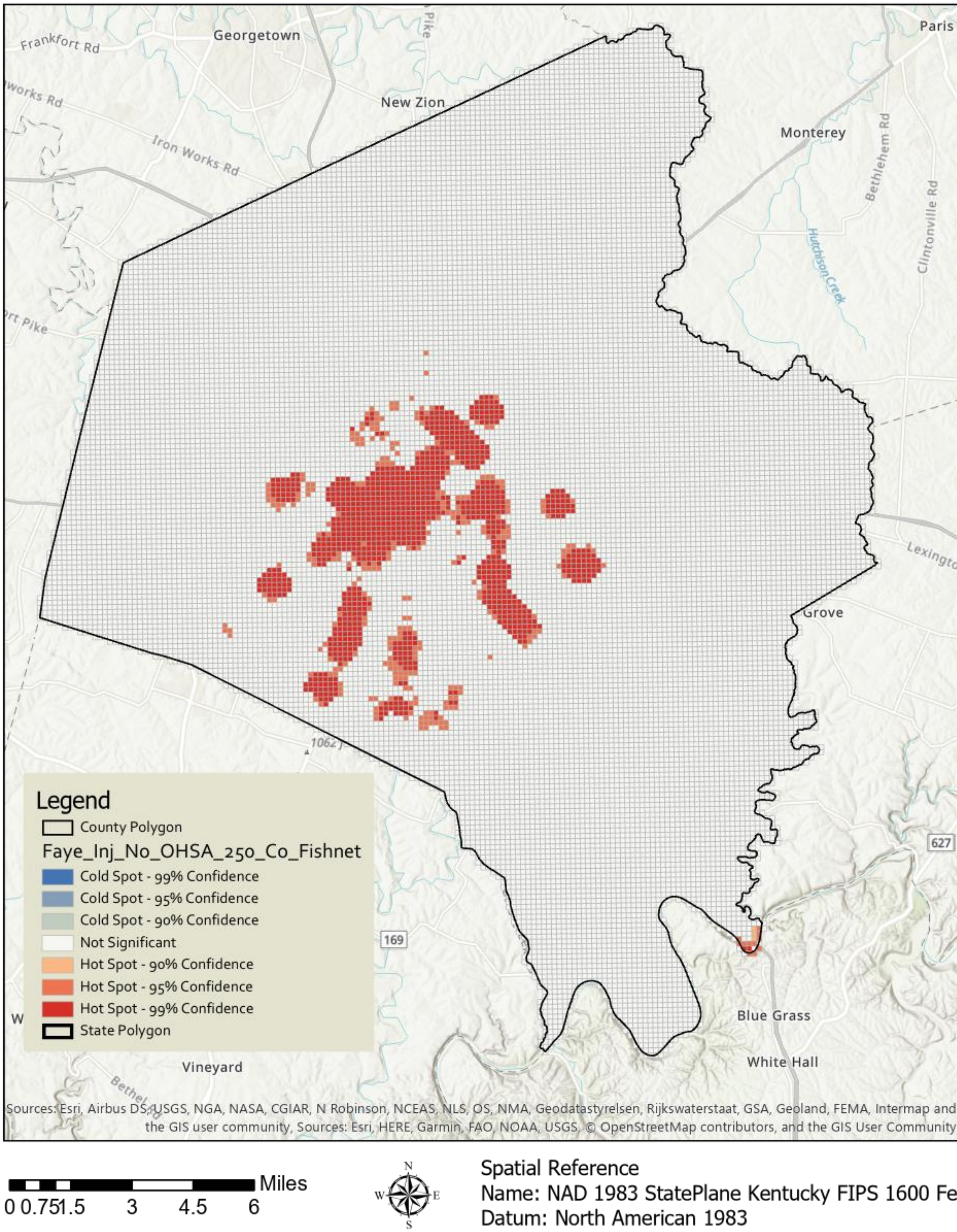


Fayette County, KY Motorcycle Collision Analysis
Optimized Hotspot Analysis: Fatality Involved Collisions
Frankfort Rd
Georgetown
New Zion
Iron Works Rd
Monterey
Paris
Bethlehem Rd
Clintonville Rd
Hutchison Creek
Lexington
Blue Grass
White Hall
Vineyard
Legend
County Polygon
Faye_Inj_Fata_OHSA_500m_Co_Fishnet
Cold Spot - 99% Confidence
Cold Spot - 95% Confidence
Cold Spot - 90% Confidence
Not Significant
Hot Spot - 90% Confidence
Hot Spot - 95% Confidence
Hot Spot - 99% Confidence
State Polygon
169
627
Sources: Esri, Airbus DS, USGS, NGA, NASA, CGIAR, N Robinson, NCEAS, NLS, OS, NMA, Geodatastyrelsen, Rijkswaterstaat, GSA, Geoland, FEMA, Intermap and the GIS user community, Sources: Esri, HERE, Garmin, FAO, NOAA, USGS, © OpenStreetMap contributors, and the GIS User Community
Miles
0 0.75 1.5 3 4.5 6
N
W
E
S
Spatial Reference
Name: NAD 1983 StatePlane Kentucky FIPS 1600 Feet
Datum: North American 1983

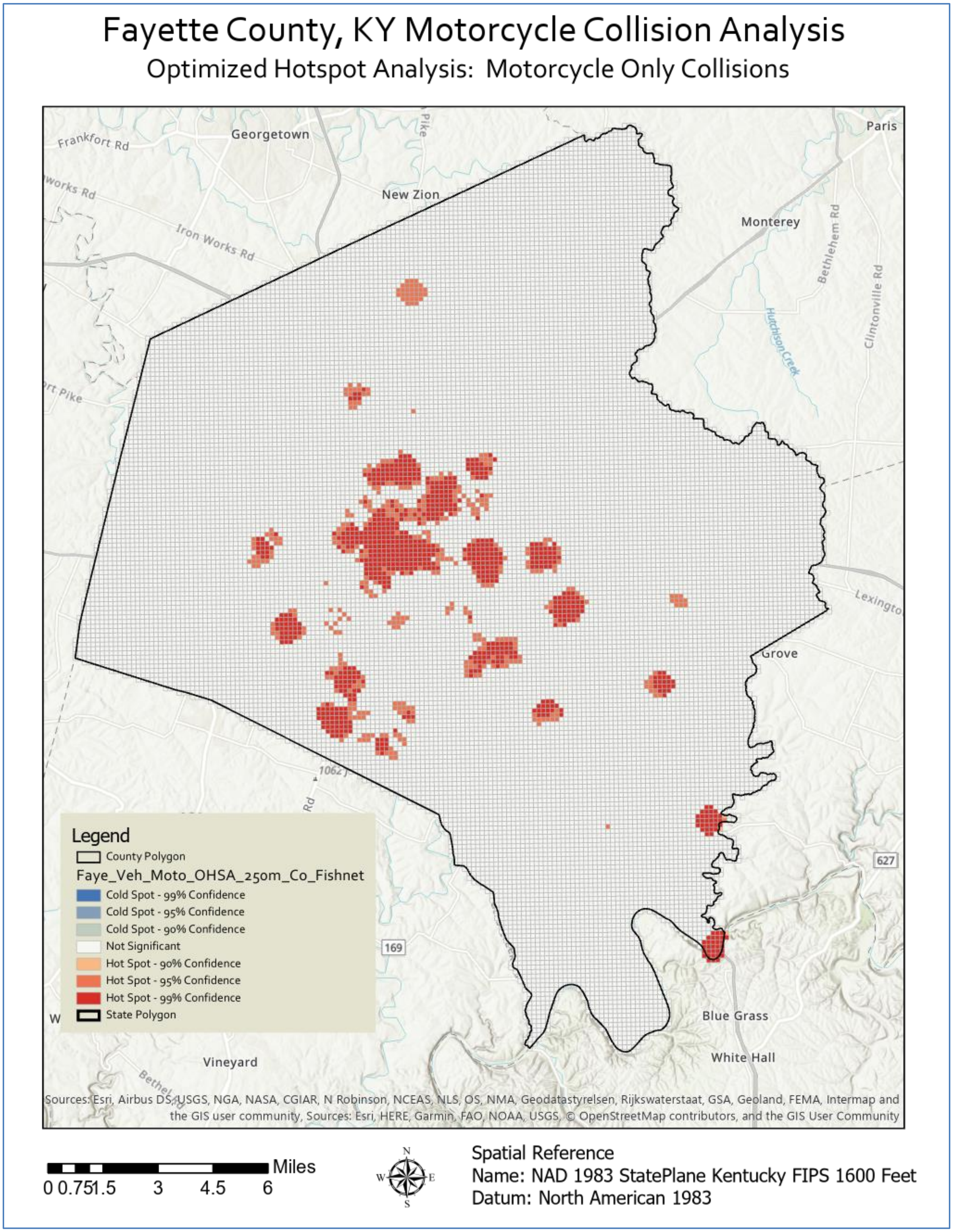

Fayette County, KY Motorcycle Collision Analysis
Optimized Hotspot Analysis: Injury Involved Collisions
Georgetown
Frankfort Rd
New Zion
Iron Works Rd
Paris
Monterey
Bethlehem Rd
Clintonville Rd
Hutchison Creek
Lexington
Grove
627
169
Blue Grass
White Hall
Vineyard
Legend
County Polygon
Faye_Inj_Inj_OHSA_250m_Co_Fishnet
Cold Spot - 99% Confidence
Cold Spot - 95% Confidence
Cold Spot - 90% Confidence
Not Significant
Hot Spot - 90% Confidence
Hot Spot - 95% Confidence
Hot Spot - 99% Confidence
State Polygon
Sources: Esri, Airbus DS, USGS, NGA, NASA, CGIAR, N Robinson, NCEAS, NLS, OS, NMA, Geodatastyrelsen, Rijkswaterstaat, GSA, Geoland, FEMA, Intermap and the GIS user community, Sources: Esri, HERE, Garmin, FAO, NOAA, USGS, © OpenStreetMap contributors, and the GIS User Community
0 0.751.5 3 4.5 6 Miles
N
W E
S
Spatial Reference
Name: NAD 1983 StatePlane Kentucky FIPS 1600 Feet
Datum: North American 1983

Fayette County, KY Motorcycle Collision Analysis

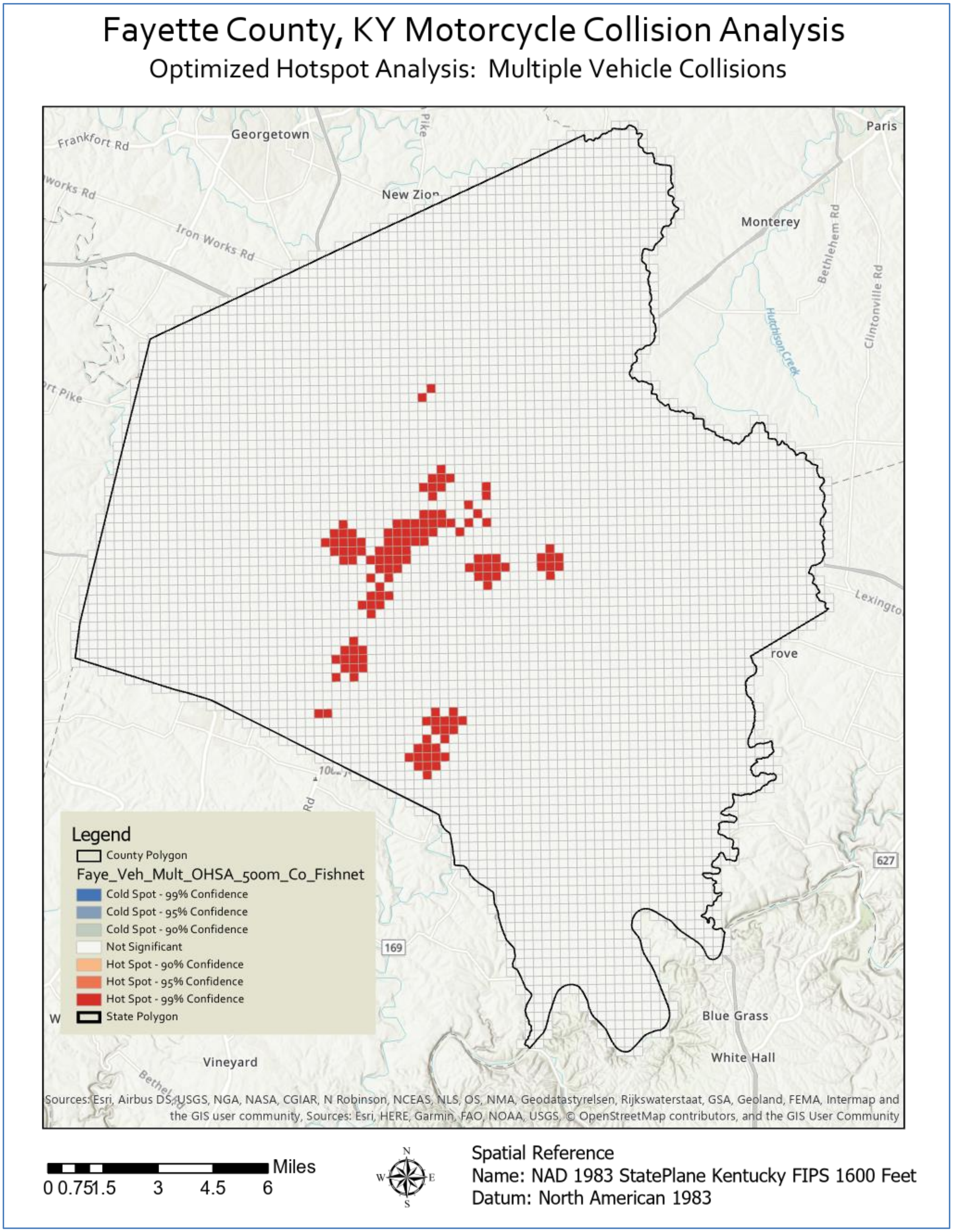
Optimized Hotspot Analysis: No Injury / Fatality Collisions



Spatial Reference
Name: NAD 1983 StatePlane Kentucky FIPS 1600 Feet
Datum: North American 1983

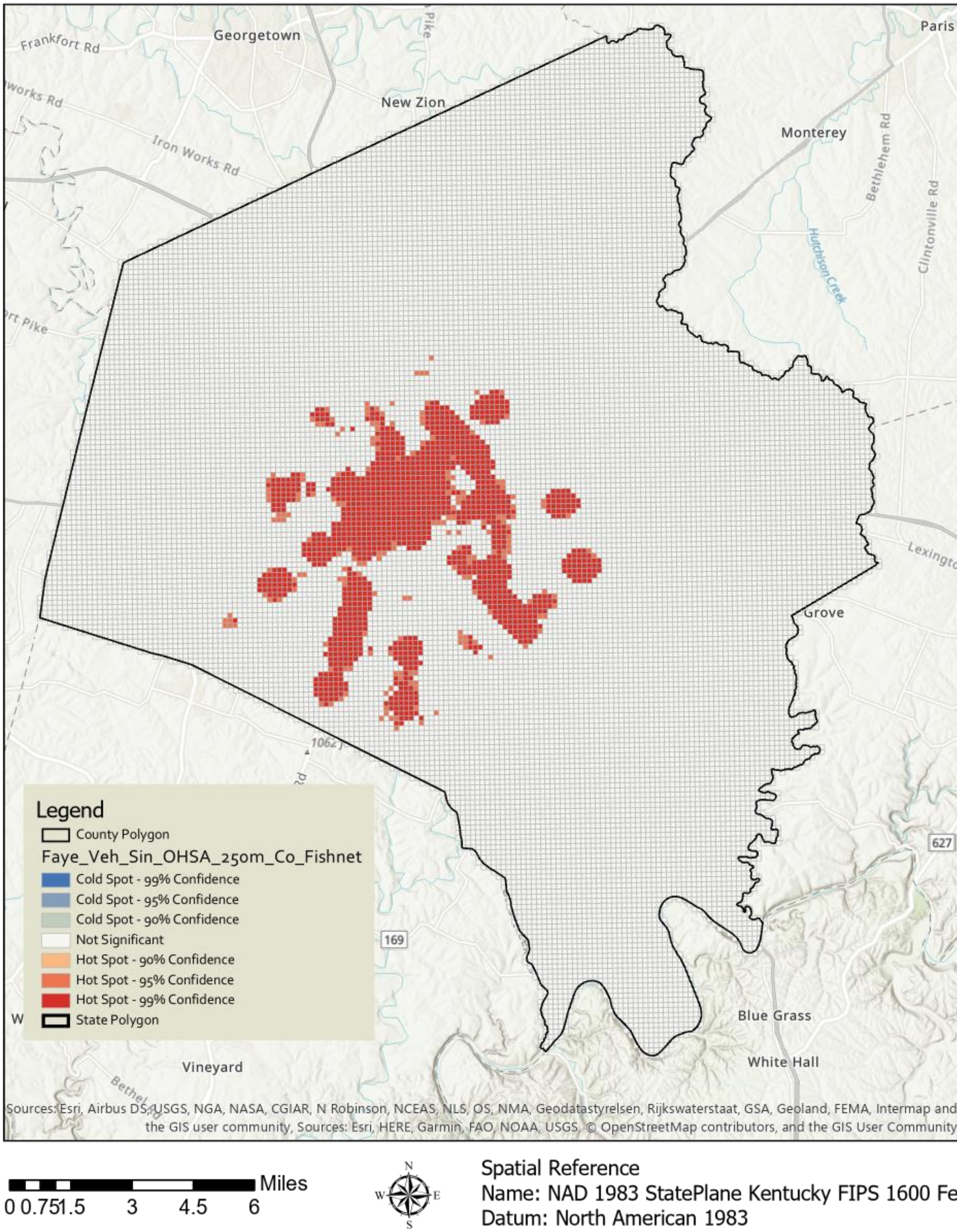


Fayette County, KY Motorcycle Collision Analysis
Optimized Hotspot Analysis: Motorcycle Only Collisions
Frankfort Rd
Georgetown
New Zion
Iron Works Rd
Monterey
Paris
Bethlehem Rd
Clintonville Rd
Hutchison Creek
Lexingto
Grove
1062
169
627
Blue Grass
White Hall
Vineyard
Legend
County Polygon
Faye_Veh_Moto_OHSA_250m_Co_Fishnet
Cold Spot - 99% Confidence
Cold Spot - 95% Confidence
Cold Spot - 90% Confidence
Not Significant
Hot Spot - 90% Confidence
Hot Spot - 95% Confidence
Hot Spot - 99% Confidence
State Polygon
Sources: Esri, Airbus DS, USGS, NGA, NASA, CGIAR, N Robinson, NCEAS, NLS, OS, NMA, Geodatastyrelsen, Rijkswaterstaat, GSA, Geoland, FEMA, Intermap and the GIS user community, Sources: Esri, HERE, Garmin, FAO, NOAA, USGS, © OpenStreetMap contributors, and the GIS User Community
Miles
0 0.751.5 3 4.5 6
N
W
E
S
Spatial Reference
Name: NAD 1983 StatePlane Kentucky FIPS 1600 Feet
Datum: North American 1983


Fayette County, KY Motorcycle Collision Analysis
Optimized Hotspot Analysis: Multiple Vehicle Collisions
Frankfort Rd
Georgetown
New Zion
Paris
Iron Works Rd
Monterey
Bethlehem Rd
Clintonville Rd
Hutchison Creek
Lexingto
rove
627
169
Blue Grass
White Hall
Vineyard
Legend
County Polygon
Faye_Veh_Mult_OHSA_500m_Co_Fishnet
Cold Spot - 99% Confidence
Cold Spot - 95% Confidence
Cold Spot - 90% Confidence
Not Significant
Hot Spot - 90% Confidence
Hot Spot - 95% Confidence
Hot Spot - 99% Confidence
State Polygon
Sources: Esri, Airbus DS, USGS, NGA, NASA, CGIAR, N Robinson, NCEAS, NLS, OS, NMA, Geodatastyrelsen, Rijkswaterstaat, GSA, Geoland, FEMA, Intermap and the GIS user community, Sources: Esri, HERE, Garmin, FAO, NOAA, USGS, © OpenStreetMap contributors, and the GIS User Community
0 0.75 1.5 3 4.5 6 Miles
N
W E
S
Spatial Reference
Name: NAD 1983 StatePlane Kentucky FIPS 1600 Feet
Datum: North American 1983

Fayette County, KY Motorcycle Collision Analysis

Optimized Hotspot Analysis: Single Vehicle Collisions



Spatial Reference
Name: NAD 1983 StatePlane Kentucky FIPS 1600 Feet
Datum: North American 1983